Air pollution and the world of work

Policies, initiatives and the current situation – a scoping and evidence review for Southeast and East Asia

SEI report
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Executive summary

Air pollution is a growing global threat to human health and, by extension, occupational health, the environment, and economies. This scoping report aims to assess the current state of knowledge of the interlinkages between air pollution and the world of work in East and Southeast Asia, in order to identify knowledge gaps to be filled through further case studies. According to the WHO, air pollution caused an estimated 6.9 million premature deaths in 2016, or more than 10% of worldwide deaths, 70% of which occurred in the Asia-Pacific region. Exposure to air pollution can be multi-layered. For many workers, the type of work they do and the conditions in which they do it is a big determinant of their exposure to air pollution beyond daily exposure to ambient (outdoor) air pollution, while certain groups also face household (indoor) air pollution. Furthermore, other factors such as socioeconomic status and gender, effect their sensitivity to its impacts.

This scoping report seeks to understand the differentiated impacts of air pollution on workers in East and Southeast Asian countries and identify evidence-based recommendations from regional case studies to help improve air quality and foster healthy employment in the context of just transitions towards a low-carbon economy. Following an introduction to the aims and scope of the report, chapter 2 presents data analysis of the current air pollution situation (sources, levels, exposure) and labour markets across 13 countries of Southeast and East Asia. Chapters 3 to 5 apply a desk review and evidence synthesis on the knowledge, policies, actions and innovations relevant to labour and air quality, including the social and health dimensions of air pollution exposure in the workplace and access to social protections. This report applies an intersectional gender lens throughout each section of the analysis and, as much as possible, considers both formal and informal work, though data and resources on informal and particularly unpaid or domestic work are limited. As a scoping study, this report does not intend to showcase solutions to the challenges identified, but rather to identify areas where further in-depth case studies may highlight ways forward.

To start, chapter 2 provides an overview of air quality and key labour market statistics in East and Southeast Asia. Of the 6.67 million global premature deaths caused at least in part by air pollution in 2019, 62% (4.14 million) were attributed to ambient particulate matter (PM) pollution, 34% (2.31 million) to household air pollution and 5% (365,000) to ambient ozone pollution. Occupational exposure to PM, gases and fumes resulted in an additional 524,000 premature deaths worldwide, while exposure to additional occupational carcinogens and asthmagens were responsible for an additional 400,000 premature deaths, meaning occupational exposure resulted in almost 1 million premature deaths in 2019, according to the Global Burden of Disease Study (2019) (Institute of Health Metrics and Evaluation, 2020a). In Southeast and East Asia, the health burden of air pollution was higher for males than females. Comparing the health burdens of the different types of air pollution exposure across the countries in East and Southeast Asia, occupational exposure to PM, gases and fumes is a lesser threat than both ambient air pollution and household air pollution exposure, but still caused more than 200,000 premature deaths in 2019, the majority of which were in China. China experienced the highest estimated health burden due to occupational exposure of PM, gases and fumes, while Cambodia suffered the highest burden from household air pollution from solid fuels and Mongolia experienced the highest health burden from ambient air pollution.

The countries in Southeast and East Asia considered in this review showed a reduction in annual ambient $PM_{2.5}$ (particulate matter with a diameter of less than 2.5 microns (μm)) concentrations in 2020, compared to 2019, likely as a result of the COVID-19 pandemic reducing activity associated with emissions, particularly from industry and transport. Mongolia had the highest annual average air pollution in both 2019 and 2020, while China had the second-highest annual average air pollution and the highest average $PM_{2.5}$ population-weighted exposure (the average concentration of $PM_{2.5}$ per person) according to the State of Global Air estimates in 2019 (Health Effects Institute, 2019). China also emitted the highest level of $PM_{2.5}$ in 2015, followed by Indonesia and Viet Nam, according to the Emissions Database for Global Atmospheric Research (EDGAR)(Crippa et al., 2019). The emissions of air pollution split by sector shows that the largest proportion of emissions for most countries comes from manufacturing and construction, while biomass burning is a major source in several Southeast Asian countries like Indonesia, Viet Nam and Thailand. Examining the link between health impacts of occupational exposure to PM, gases and fumes, and the types of work done by employees, we find that in countries where a large share of the workforce works in manufacturing or agriculture (Cambodia, Myanmar, Viet Nam), there is greater occupational exposure of PM, gases and fumes. In comparison, countries which have a large proportion of the workforce in the service industry (Singapore, Brunei Darussalam, Malaysia) experience a much lower health burden from occupational exposure, as well as ambient and household air pollution overall.

Chapter 3 considers the social dimensions of air pollution in the world of work by answering the question: "What is the state of knowledge on the social dimensions of air pollution in the world of work?" on a global level. It maps out thematic topics and their prevalence in the literature on the social dimensions of air pollution in workspaces. It specifically examines the disproportionate impacts of air pollution on employment and workforce, characterized by sex, age, ability, ethnicity, race and economic status. The literature review adopted principles from systematic review and mapping methodologies to carry out a comprehensive review that seeks to minimize bias and maximize transparency. Based on 50 papers that met the inclusion criteria, the review highlights four main findings. Firstly, the impacts of air pollution are largely framed in research by a public health and medical perspective, rather than by the day-to-day experiences of exposed groups. Secondly, research on the impacts of air pollution and employment mainly focus on the formal labour force, while the informal labour force (workers with no contract and often unrecognized by social security systems) remains largely underexamined, particularly within urban settings. Thirdly, studies of gender and workers' exposure to air pollution tend to be biased towards women and their presumptive gendered role as homemakers, while overlooking men and ways in which gender identity intersecting with socioeconomic factors determine exposures – for example, through men's predominant involvement in traffic-facing roles which involve high pollution exposure in addition to their exposure to domestic air pollution. Lastly, hierarchies within a sector or workplace influenced by gender, social class and other factors also result in unequal exposures to air pollution, with lowest-skilled workers usually the most exposed.

Chapter 4 seeks to answer the question: "What are the health impacts of air pollution on different groups of workers in East and Southeast Asia?" It also considers the vulnerability, differential impacts and occupational exposure to air pollution of different groups in the region. This chapter is split into two sections. One focuses on occupational health impacts of air pollution and the other focuses on the occupational exposure itself. The first section reviews the existing evidence on the occupational health impacts of air pollution in Southeast and East Asia using a systematic evidence-mapping method. Air pollution, as widely studied globally, poses a serious threat to human health through carcinogenic and mortality risks on respiratory, cardiovascular, neurological and reproductive systems. The review in this chapter, based on 45 papers which met inclusion criteria, finds that the health impacts of air pollution are strongly mediated by social axes of stratification such as class, job roles, gender, age and place of residence.

In terms of health impacts from occupational exposure reviewed in the second section of Chapter 4, the 52 included studies indicate that these impacts are directly related to the concentration, origin and exposure level to a certain pollutant. The amount of time a person is exposed to a certain pollutant elevates health impacts. Pollutants from multiple sources in the same area can compound and drastically raise the level of exposure. Most of the research found in the literature focuses on outdoor air pollution from traffic exhaust and ambient air pollutants, emphasizing groups such as policemen and drivers. The lack of gender-specific research in the literature highlights the need for more studies on gendered and intersectional impacts of air pollution. What the literature review found relates predominantly to practical and individual strategies to mitigate immediate harm, such as awareness, use of protective equipment and change of working patterns to reduce health impacts on workers; there was little available literature that assessed or addressed exposure from an upstream prevention or wider workforce angle, such as broader health and social protection coverage for workers in polluted environments.

Chapter 5 investigates what policies exist with regards to air pollution control in the region, and then moves on to labour policies. The policy review finds that most countries in Southeast and East Asia have a legal framework specific to air pollution – though in certain countries, this falls under broader environmental quality legislation. In terms of ambient air quality standards, four countries do not have any standards, while none of the countries have set their $PM_{2.5}$ standards at the updated 2021 WHO guideline level, which is a maximum of 15 micrograms per cubic meter (μg/m³) over 24 hours or an average annual exposure of 5 μg/m³ . The review suggests that the low-income countries in the region (Cambodia, Lao PDR and Myanmar) remain the least-advanced in their implementation of clean air measures, including Euro standards and fuel sulphur content, and still lack comprehensive policy frameworks to facilitate this. However, Cambodia is about to publish its first Clean Air Plan, which will go some way into targeting some of these key emissions sources with an aim of reducing air pollution nationally.

The review of labour and social security policies revealed that although air pollution is acknowledged as creating hazardous working conditions, not all kinds of air pollution (e.g. gas and fumes, chemical substances or PM) are equally regarded as occupational health risks. Also, compensation for occupational diseases caused by air pollution is not always included. The labour policies often target industrial and waged workers, overlooking informal workers exposed to various pollution sources. Moreover, access to social security is granted through formal employment and employers, which compels informal workers to shoulder the burden of medical care themselves.

In the review of non-governmental initiatives that address air pollution, we found these initiatives often do not consider occupational health and safety or working condition issues. Instead, they focus on measuring and monitoring pollutant levels (e.g., the concentrations of each particle) and modelling scenarios (e.g., transport and greenhouse gas emissions, or GHG) in gathering data for policy recommendations. Moreover, some technocratic solutions to air pollution these initiatives propose overlook dimensions of vulnerability in the world of work, such as workers' differentiated exposure to air pollution, lack of access to healthcare, and social and worker protection services. As the main donors of the projects are global financial and development institutions, they significantly affect how inequalities are addressed in framing problems and solutions for air pollution. Local or grassroots actors, who have a better contextual understanding of air pollution impacts on different social groups and individuals, seem to have limited access to program implementation funds.

The review of policies on urban public space reveals that issues regarding air pollution and the informal sector are tied to access to physical spaces and facilities, and solutions are largely structural solutions such as traffic management and public transport, or relocation of street vendors. This access approach in public space policies does not effectively address causes of air pollution, and neither does it recognize exposure and impacts of air pollution on informal sector workers.

Chapter 6 presents a summary of key findings and then highlights four issues identified by the review regarding the framing of occupational health and safety. Rather than technical limitations, these issues reflect limitations in how the literature and policy to date engages with (or fails to engage with) gender and social equity dimensions of air pollution. First, there is a near absence of consideration for workers operating in the informal sector, both from a policy perspective and in research. This may be a self-perpetuating problem: if researchers and statistical systems do not examine occupational exposure of informal workers, no findings will exist to push the need to protect informal workers from air pollution, and therefore no legal or policy framing will be developed to address their needs.

Secondly, there remain gender stereotypes in framing research around occupational exposure. Most of the research on impacts of indoor air pollution focuses on women's domestic care duties and exposure to cookstove air pollution. Where there is research on occupational exposure impacts on women, the emphasis is on impacts on reproductive health.

Thirdly, there is an emphasis on the physical impacts of occupational exposure to air pollution. There is little consideration of the possible psychological impacts of air pollution, and this is reflected in health and safety legislation and regulation which considers only the physical health impacts of air pollution.

Finally, the offered solutions to occupational air pollution exposure emphasize technical and physical solutions to mitigate emissions and exposure at the worksite. Addressing ambient air pollution remains a gap, which negatively affects outdoor workers – many of whom operate in the informal sector, whether in urban or rural settings. Solutions also do not target the social inequalities in exposure to, and impact of, air pollution, which could require upstream intervention, such as social welfare systems or promotion of green industry.

The scoping review identified the following areas that would benefit from further in-depth research (i.e. via case studies):

- Air pollution's impacts on informal workers.
- The workers' perception of their experiences of air pollution, as the knowledge of impacts of air pollution are largely framed by the public health and medical discipline rather than day-to-day experiences of exposed groups.
- Differentiated impacts of air pollution on workers who are transgender or non-binary, and how discriminations around workers' sexuality and gender-identity can lead to different types of work assigned and, consequently, unequal exposure to air pollution.
- Occupational health impacts of specific worker groups in certain geographies, including women engaging in paid work, farm and other rural workers, workers in small towns, or from smaller and poorer countries within the region, in informal occupations, child laborers, internal migrant workers or disabled workers.
- The impact of air pollution on child laborers and its subsequent gendered impacts (e.g., increased burden on caretakers).
- The physical health impacts on non-respiratory and cardiovascular system and on mental health.
- Developing more varied methodologies to study the impact of occupational air pollution to capture the socio-economic dimensions, such as more nuanced, qualitative work to analyse intra-firm differences in job roles and hierarchies impacting exposure, stratified based on race and gender.
- The impact of outdoor air pollution (as opposed to indoor air pollution) on labour.
- Whether the size of enterprises and health coverage affect the impacts of air pollution at work.
- A broader definition of occupational health that includes home-based workers, workers residing near polluting industries and impacts of pollution mitigation strategies.
- The extent that air pollution policies consider workers' exposure.
- Addressing air pollution and climate change side-by-side while transitioning to green jobs.

Chapter 1: Introduction

1.1 Background

Air pollution is a growing global threat to human health and, by extension, occupational health, the environment and economies. While estimates vary according to different sources, according to the WHO, outdoor (also known as ambient) air pollution caused an estimate 4.2 million premature deaths in 2016 worldwide, while household air pollution caused about 3.2 million deaths. An Organisation for Economic Co-operation and Development (OECD, 2016) report on the projected economic consequences of outdoor air pollution illustrates the ways in which the increase in air pollution will substantially affect the economy, stating that, "the market impacts of outdoor air pollution, which include impacts on labor productivity, health expenditures and agricultural crop yields, are projected to lead to global economic costs that gradually increase to 1% of global GDP by 2060" (OECD, 2016, p. 1). The World Bank (2016) indicated that the magnitude of socioeconomic costs was highest in the Southeast Asia region and amounted to 7.5% and 7.4% of GDP in 2013 for East Asia and the Pacific and South Asia, respectively. This data does not include the impact of lost productivity due to absenteeism and other factors; therefore, the true cost is likely higher. Against this backdrop, several of the UN Sustainable Development Goals (SDGs) encapsulate the problem of air pollution and its subsequent human health impacts, including SDG 3 (global health and wellbeing), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure) and SDG 10 (reduced inequalities).

For many workers, the type of work they do and the conditions in which they do largely determines their exposure to air pollution beyond daily exposure to ambient air pollution. Their socioeconomic status and occupation also affects their sensitivity to its impacts. For example, a labourer who lives in a highly polluted city, but also works in a brick kiln or as a street sweeper with no access to protective equipment, will face greater exposure than an office worker in the same city. People exposed to air pollutants face an increased risk of suffering from serious health effects such as cardiovascular disease, stroke, lung cancer and damage to their immune, neurological, reproductive and respiratory systems. Furthermore, preliminary studies have pointed to the correlation between long-term exposure to $PM_{2.5}$ and the increase in Covid-19 death rate (X. Wu et al., 2020). These direct personal health impacts also influence worker productivity, employment, the economy and society.

East and Southeast Asia are seeing various transitions in the work world, propelled by labour migration (particularly rural-to-urban migration), technological development and evolutions in the type of work available. This shift not only affects paid work, but also has profound implications for unpaid labor as societal or family dynamics change alongside broader labour patterns. Against this backdrop, it is more relevant than ever to explore the impacts of air pollution on occupational health and productivity across diverse and shifting population groups and work sectors, in order to take the appropriate mitigating actions. This includes considering the roles and responsibilities of employers, and the impacts on their productivity and financial viability, but also government agencies and other actors, particularly regarding the rights of informal and migrant workers. Additionally, globalization, technological advancements, demographic shifts, and environmental changes arising from climate change and urban expansion all factor into how air pollution can and should be addressed within the world of work.

While gender inequality embedded in social economic systems causes unequal exposure and vulnerability to air pollution, research on gender and air pollution has mostly focused on women's exposure to indoor (i.e., point source) air pollution (i.e., via exposure to inefficient cookstoves as primary caregivers and domestic workers). However, less is known on the gendered impacts of air pollution exposure by women, youth and migrant workers outside the domestic sphere who are over-represented in the informal economy in Asia, such as street vending, daily wage labour and agriculture. To fully consider the impacts of air pollution exposure for vulnerable sub-groups and the link to the professional world, it is important to consider the overall exposure of different people, including the amount of time people spend in their homes, outdoors travelling to their occupation and exposure in their workplace. We also need to understand the concentrations of pollutants in each environment. Health impacts, and therefore impacts on productivity, is related to the overall exposure of the workers, but is also related to exposure and health impacts on their children. This is because productivity is defined by workdays lost, but also school days missed where the parent has to stay at home when their children are ill, with asthma, for example. Evidence indicates that workplace productivity is correlated with local air pollution levels. Additionally, there remain large gaps in understanding the extent to which occupational exposure (point source) to air pollution is a problem in terms of economic costs, due to limited data collection on this topic and the many varieties of occupational air pollutants.

Understanding the different impacts of air pollution on the work world in East and Southeast Asian countries, and identifying evidence-based recommendations from regional case studies, will help improve air quality, as well as the quality and quantity of employment in the context of just transitions towards a low-carbon economy. Such knowledge could be added to the evidence base needed by policy-makers, employers and labour organizations and practitioners working in the environment, labour and health sectors to mitigate the gendered impacts of air pollution in work.

1.2 Aim and structure of the report

This scoping report assesses the state of knowledge on the interlinkages between air pollution and the world of work in an East Asian and Southeast Asian context. The purpose is to evaluate, based on the evidence gathered, which countries and sectors need further investigation, and what gaps remain in the collective knowledge, which can be explored through additional case studies.

To achieve this, the scoping review assesses the regions from several angles relevant to labour and air quality. The different elements of the report are summarized in the table below: As outlined in the table, this scoping is done through desk research and evidence synthesis on the knowledge, policies, actions and innovations relevant to labour and air quality, as well as data analysis of air pollution (sources, levels, exposure) and labour markets across Southeast and East Asia. The scoping review is guided by an intersectional gender lens that considers the multiple and complex ways that various identities (e.g. class, race, geographies) mediate gendered experiences of air pollution.

The reviews focus on gathering existing data and evidence about the current labour market (including key sectors of employment and their shares of employment of different population groups, working conditions and occupational health, the key groups and associations representing workers and employers and their roles), air quality levels (including data from monitoring stations or satellite monitoring where available, especially outdoor air but also, where feasible, indoor and workplace air quality), and general background information on different population groups and the particular vulnerabilities they may face in relation to work. It includes estimations of the exposure of different population groups, including women, in different socio-economic groups and occupations.

As a scoping study, this report does not intend to showcase solutions to the challenges identified, but rather to identify areas where further in-depth case studies may highlight ways forward. A key limitation of the scoping review is access to databases, as only the Scopus databases were used to identify literature. In addition, labour statistics on informal and domestic labour are often scarce or incomplete, which limits the extent to which the statistics can illustrate patterns. Finally, only English language documents are included in the study, which may have omitted many relevant documents published in the assessed region's many languages.

Chapter	Sub-question	Method and output
Chapter 2	What are the regional patterns of air quality and health burdens across East and Southeast Asia?	A regional scoping of air quality and labour statistics to perform a classification of countries based on labour market information, air pollution hotspots and key sectors. This is done by extracting data from key sources including: data on labour force participation rate and the share of employment by economic activity from International Labour Organisation (ILO) databases (ILO 2019), emissions of total annual PM2.5 (particulate matter with a diameter < 2.5 μm) and the contribution of each sector to total PM2.5 emissions from the Emissions Database for Global Atmospheric Research (Crippa et al., 2019), and estimates of health impacts for different population subgroups due to ambient, household and occupational air pollution exposure from the Global Burden of Disease Study (Institute of Health Metrics and Evaluation, 2020a). Information on ambient annual average air pollution in countries and cities was taken from the State of Global Air 2019 and State of Global Air 2020 reports (Health Effects Institute, 2019, 2020) This classification can give an idea of which countries have the worst air quality and which sectors contribute the most to this air pollution.
Chapter 3	What is the state of knowledge on the social dimensions of air pollution in the world of work?	A semi-systemic literature review of the social dimensions of the impacts of air pollution in the region, including gender, migrant status and other considerations. The review for this section takes a global approach, as it is helpful to have a broader understanding of the state of knowledge worldwide on this subject in order to get an idea of how the topic of air pollution, labour and its social dimensions have been approached in general. By having this broad overview, the current studies globally can also point to ways that this topic can be explored in the East and Southeast Asian region.
Chapter 4	What are the differentiated impacts, vulnerabilities and occupation exposure to air pollution of different groups across East and Southeast Asia?	A semi-systematic literature review of workers' differentiated vulnerability to air pollution, including the health impacts, and a review of occupational exposure to air pollution in East and Southeast Asia.
Chapter 5	What are the existing policies and initiatives regulating air pollution, labour and workplace exposure in East and Southeast Asia, and what are some of the key gaps?	A review of the existing policies addressing air pollution in the region, including with specific consideration to work, such as policies relevant to occupational exposure to pollution, policies regulating use of public space (of particular relevance to informal sector workers in urban settings) and existing initiatives seeking to address occupational air pollution. The Actions on Air Quality report (UNEP, 2016) was used as a baseline for the searches.
Chapter 6	What are the implications of the research and what remains to be done?	A summary and discussion of the key findings, including the remaining knowledge gaps.

Chapter 2: An overview of air quality and key labour market statistics in East and Southeast Asia

By Jessica Slater

This chapter gives an overview of relevant labour market indicators in East and Southeast Asia and considers air pollution hotspots, the main contributing sources, and the health burden associated with air pollution. Using this information, we rank countries according to average air pollution ($PM_{2.5}$) concentrations and emissions and align this with information about employment in each country.

2.1 Methodology

The main methodology used in this chapter was extracting data from key sources, including: data on labour force participation rate and the share of employment by economic activity from International Labour Organisation (ILO) databases (International Labour Organization, 2019); emissions of total annual $PM_{2.5}$ (particulate matter with a diameter of less than 2.5 microns) and each sector's contribution to total $PM_{2.5}$ emissions from the Emissions Database for Global Atmospheric Research (Crippa et al., 2019); and estimates of health impacts for different population subgroups due to exposure to ambient, household and occupational air pollution from the Global Burden of Disease Study (Institute of Health Metrics and Evaluation, 2020a). Information on ambient annual average air pollution in countries and cities was taken from the State of Global Air 2019 and State of Global Air 2020 reports (Health Effects Institute, 2019, 2020).

In this work, we primarily focus on $PM_{2.5}$ as the main air pollutant for several reasons: firstly, this data is most frequently measured at air quality monitoring stations and is a common metric for determining levels of total air pollution. Secondly, sources of $PM_{2.5}$ are varied and so can encompass a wide range of emissions. Finally, though gaseous pollutants such as nitrogen oxides (NOx) and ozone (O_3) are linked to health effects, including respiratory disease, evidence suggests that $PM_{2.5}$ inflicts the highest burden of disease and is linked to the largest range of health impacts (Institute of Health Metrics and Evaluation, 2020a). Details of the specific methodology and limitations of the data used for each element is briefly outlined below.

2.1.1 International Labour Organisation (ILO) statistics database

The International Labour Organisation (ILO) collect data on labour force, working conditions, poverty, unemployment, and workplace health and safety, among others. The aim of analysing statistics on labour in this chapter is to understand key labour sectors in each country and provide an overview of the workforce and labour market, disaggregated by sex. Understanding the key work areas would then allow for understanding which groups may be most at risk of occupational exposure to air pollution and other occupational health and safety risks, as well as understanding the key sectors that contribute to a country's economy, which is important particularly as countries continue to develop. Key labour market statistics used in the analysis are details of employment, specifically disaggregated into economic activities and by sex; national adult and youth labour force participation rate; and informal employment as a percentage of total employment. This allows for comparison of workforce characteristics in different countries.

In this work labour force participation rate means the proportion of a country's working age population (disaggregated by sex) that engages actively in the labour market, either through working or actively looking for work. We also present data on employment by economic activity disaggregated by sex. This splits the workforce into specific subsectors, according to International Standard Industrial Classification (ISIC), which can be aggregated and are presented in this analysis in 6 categories: Agriculture, Forestry and Fishing (ISIC Rev. 4 A), Manufacturing (ISIC Rev. 4 C), Construction (ISIC Rev. 4 F), Mining and Quarrying and Utilities (ISIC Rev. 4 B,D,E), Business Services (ISIC Rev. 4 G-N) and Public Services (ISIC Rev. 4 O-U).

More detail on the activities in each of these subsectors are contained in the updated ISIC rev 4 documentation (ISIC, 2008). We also analyse data from the ILO on people employed informally, which can encompass a range of different roles and can also include informal employment in the formal sector. Generally, someone in informal employment will not be covered by social security, won't have entitlement to paid annual or sick leave and is unlikely to have a written employment contract (ILO Glossary). Much of the data collected by ILO relies on labour force or household surveys, so a potential limitation may be variation in responses between countries. In several countries, such as China, data was not available. Therefore, to perform a more complete analysis of employment in different sectors across the countries, the employment by economic activity statistics presented in Figure 2.1 uses ILO modelled estimates for 2019. This data has limitations, especially when comparing countries, as it is sometimes not based on official surveys. However, as data was limited in this area for several countries, using these estimates allows us to examine employment by economic activity across all the countries assessed in this work.

Key labour indicators, including labour force participation rate, employment by economic activity and percentage of employment in the informal sector (disaggregated by sex) were analysed for each country to analyse the overall picture of work for both men and women in Southeast and East Asia. Identifying the sectors where most males and females are employed, and identifying the sectors responsible for the largest emissions of $PM_{2.5}$ in each country, allows for analysis of key occupations where exposure to air pollution may be high. In addition, identifying the percentage of employment in the informal sector will identify the number of people employed who are unlikely to be covered by health and safety regulations and who may be more at risk of occupational exposure or injury.

2.1.2 Global Burden of Disease (GBD) 2019

The Global Burden of Disease Study 2019 quantifies causes of death, disease and injury due to 87 risk factors split by age and sex in 204 countries and territories worldwide. The 87 risk factors are grouped into different levels. For example, air pollution is considered a high-level risk, encompassing household air pollution from solid fuel use, ambient PM pollution and ambient ozone (O_3) pollution. Occupational exposure to PM, gases and fumes is covered under the higher-level occupational risk, which also covers occupational injuries and noise pollution, as well as exposure to specific carcinogens, asthmagens and asbestos. For the calculated risk due to ambient particulate matter (PM) and household air pollution, the risk is linked to nine health effects, including cardiovascular disease, respiratory infections and tuberculosis, chronic respiratory diseases, maternal and neonatal diseases, diabetes and kidney infections. However, the risk due to ambient ozone pollution exposure and occupational exposure to PM, gases and fumes is only associated with chronic respiratory diseases. At least for occupational exposure to PM, gases and fumes, in certain cases this is associated with similar health risks of ambient PM or household air pollution exposure and is therefore linked to similar health risks. Consequently, a limitation of using the GBD study for estimates of the health effects of different types of labour may be an underestimation in the total impact due to the limited effects considered (Institute of Health Metrics and Evaluation, 2020a).

2.1.3 Emissions Database for Global Atmospheric Research (EDGAR)

The Emissions Database for Global Atmospheric Research (EDGAR) provides estimates of emissions of both GHGs and a wide variety of air pollutants from a variety of source sectors, including industry, transport and agriculture. For energy sources, estimates of emissions are based on International Energy Agency (IEA) data, while agricultural emissions are based on data from the Food and Agricultural Organization (FAO). However, emissions from large scale biomass burning and forest fires, and sources and sinks from land use change and forestry, are not included. This will be a limitation of using EDGAR as a data source, especially because in several Southeast Asian countries, biomass burning and forest fires might contribute significantly to air pollution (Crippa et al., 2019).

2.2 Results

2.2.1 Country ranking by ambient $PM_{2.5}$ concentrations

According to the 2020 World Air Quality Report (IQAir, 2020), Mongolia had the worst annual average air quality (highest $PM_{2.5}$ concentrations) in 2020 out of all countries in Southeast and East Asia, followed by Indonesia, China and Myanmar (Table 2.1). In all countries in Southeast and East Asia, annual average $PM_{2.5}$ concentrations were lower in 2020 compared to 2019, suggesting an improvement in air quality, likely as a response to the COVID-19 pandemic and associated lockdowns reducing activity and, consequently, emissions. According to the report, in 2020, none of the countries outlined in Table 2.1, achieved the World Health Organization's (WHO) air quality guidelines for annual exposure, which was made more stringent to $PM_{2.5}$ < 5 µg/m^3 in 2021. However, annual average $PM_{2.5}$, although a good general description of air quality in a country, does not give the full picture of air pollution, particularly in countries in East and Southeast Asia, where there is significant seasonal variation in air pollutant concentrations. Furthermore, this metric can underestimate exposure to air pollution for certain population groups (e.g., people living in cities or close to pollution sources, where pollution is often higher). Consequently, a large proportion of people will be exposed to higher levels of pollution than the country average.

Air pollution does not observe political borders but moves between countries and across regions. Consequently, emissions of air pollutants in one country can worsen air pollution in another and result in negative health impacts for that country's population. Consequently, efforts to tackle air pollution must involve a coalition of countries and take a regional approach. In East Asia, all of the 15 top polluted cities are in mainland China, despite Mongolia having the worst air quality on average in 2020. However, China has the most $PM_{2.5}$ monitoring stations (2,200 in 2019) compared to Mongolia (39 in 2019). This means air quality may be worse in some areas of Mongolia, but less overall data is available. The Republic of Korea, although having better average air quality than both China and Mongolia, still has poor air quality with high concentrations compared to other OECD countries [61 of the 100 most polluted cities in OECD countries are in South Korea (KBSWorld, 2020)] and annual average $PM_{2.5}$ concentrations of 19.5 µg/m^3), which is almost double the WHO recommended guidelines of 10 µg/m^3 (World Health Organization, 2006).

In Southeast Asia, three of the top 15 polluted cities are in Indonesia, 10 are in Thailand and the remaining two are in Viet Nam. Thirteen of the least-polluted cities in 2020 were located in Malaysia, which also had one of the lowest annual average $PM_{2.5}$ concentrations in Southeast Asia in 2020 (Table 2.1). Thailand and Malaysia were reported to contain the largest AQ monitoring networks, while in Myanmar, key air pollutants were only monitored in the cities of Yangon and Naypyitaw. Cambodia and Lao PDR, meanwhile, have no official government monitors, so measurements rely on non-governmental monitors, which although a good source of data, may be less reliable than official state measurements. In Indonesia, the country with the second-highest annual average $PM_{2.5}$ concentrations, the main sources of pollution according to the 2020 World Air Quality report are seasonal agricultural burning, seasonal forest fires and open burning of household waste. Meanwhile, the rapid development of the capital city Jakarta has led to a 66% increase in $PM_{2.5}$ concentrations between 2017 and 2019 (Health Effects Institute, 2019, 2020). Indonesia also had the second-highest $PM_{2.5}$ emissions at 1.55 million metric tons. Due to both the high emissions and high concentrations in this country, this suggests that a major source of pollution may come from the country itself rather than neighboring countries (though this could also be a key source). In Thailand, the capital city of Bangkok has seen an improvement in air pollution during the last few years, however in other cities (Chiang Mai and Nakhon Ratchasima), air quality is worsening. The main causes of poor air quality in Thailand are vehicles, factories, construction and waste burning year-round, as well as open agricultural burning, which causes spikes in pollution from November to March within the country and from neighbouring countries such as Myanmar, Cambodia and Indonesia (Nikam et al., 2021). This leads to regional variation in air quality throughout the country, with the top five most-polluted Thai cities located in the agricultural north of the country. Viet Nam had the second-highest $PM_{2.5}$ concentrations in Southeast Asia, with Hanoi also being the second-most polluted capital city after Indonesia, with annual average $PM_{2.5}$ concentrations of 37.9 μg/m^3 compared to 39.6 μg/m^3 in Jakarta (Health Effects Institute, 2020).

All countries, particularly those in Southeast Asia, experienced significant seasonal variations in $PM_{2.5}$ concentrations associated with the wet and dry seasons. This means that the peak concentrations in the dry season are likely to be higher than the annual average concentrations, which will be reduced by the lower pollution concentrations in the wet season (Health Effects Institute, 2020).

Table 2.1: Annual average PM2.5 concentrations from the State of Global Air report in 2019 and 2020 by country or administrative area and capital city (where applicable), ranked from highest to lowest country concentrations in 2020 (Health Effects Institute, 2019, 2020). Data was not available for Brunei Darussalam and Timor-Leste.

Country (Capital city)	2019 annual average $PM_{2.5}$ (μg/m^3)	2020 annual average $PM_{2.5}$ (μg/m^3)
Mongolia (Ulanbataar)	62.0 (62.0)	46.6
Indonesia (Jakarta)	51.7 (49.4)	40.8 (39.6)
China (Beijing)	39.1 (42.1)	34.7 (37.5)
Myanmar (Yangon)	31	29.4
Viet Nam (Ha Noi)	34.1 (46.9)	28.0 (37.9)
Lao PDR (Vientiane)	22.4	23.1
Thailand (Bangkok)	24.3 (22.8)	21.4 (20.6)
Cambodia (Phnom Penh)	21.1	21.1
Republic of Korea (Seoul)	24.8 (24.8)	19.5 (20.9)
Macau	23.5	17.8
Malaysia (Kuala Lumpur)	19.4 (21.6)	15.6 (16.5)
Hong Kong	20.3	15.4
Taiwan (Taipei)	17.2 (13.9)	15.0 (12.6)
Philippines (Manila)	17.6 (18.2)	12.8 (13.1)
Singapore	19	11.8

Comparing Tables 2.1 and 2.2, which show annual average $PM_{2.5}$ concentrations and estimated $PM_{2.5}$ emissions, most countries that have high annual average $PM_{2.5}$ emissions also have high $PM_{2.5}$ concentrations, which is to be expected. However, for certain countries, this is not the case. For example, Mongolia has one of the lowest total anthropogenic $PM_{2.5}$ emissions out of the countries identified, but it had the highest annual average $PM_{2.5}$ concentrations (Table 2.1). Meanwhile, emissions from China are an order of magnitude higher than Indonesia, despite having lower annual average $PM_{2.5}$ concentrations. For the case of Mongolia, this may be due to the incidence of dust storms which, in the spring, can contribute significantly to PM pollution, while vegetation fires are also believed to be a large source of $PM_{2.5}$ emissions (Amarzaya et al., 2015). Furthermore, in Ulaanbaatar, the capital city of Mongolia, a large proportion of air pollution in winter has been found to be due to informal coal burning for heating in urban settlements. Consequently, due to its informality, this source may not be reflected in the EDGAR database.

Table 2.2: Estimated of total emissions of PM2.5 in 2015 by country (Crippa et al., 2019).

Country	EDGAR $PM_{2.5}$ emissions in gigagrams (Gg)
China	11 055.19
Indonesia	1550.37
Vietnam	663.75
Thailand	530.4
Philippines	337.2
Myanmar	280.28
Rep. of Korea	172.64
Cambodia	143.8
Taiwan	110.6
Malaysia	86.1
Hong Kong	67.3
Lao PDR	55.8
Mongolia	25.85
Singapore	14.42
Brunei Darussalam	1.04
Macau	0.6

2.2.2 Contribution of different sectors to $PM_{2.5}$ emissions

The EDGAR emissions database provides information for some of the key polluting sectors and provides an idea of which workers or subgroups may be the most exposed. In most countries, three-quarters of $PM_{2.5}$ emissions come from the top three source sectors. In East Asia, manufacturing, industry and construction are the largest sources of $PM_{2.5}$ emissions for several countries (China, Republic of Korea and Singapore), and for most other countries it is electricity and heat production (Mongolia, Taiwan and Hong Kong). In most Southeast Asian countries, biomass burning is the major contributor to total $PM_{2.5}$ emissions, such as in Thailand, Philippines, Cambodia, Lao PDR and Viet Nam. It is the second-highest source of $PM_{2.5}$ emissions in Myanmar and Indonesia. Major other sources of $PM_{2.5}$ emissions in these countries are manufacturing, industry, construction and undefined other sectors (Annex 1).

2.2.3 Relevant labour market indicators by country

The International Labour Organisation (ILO) provides information on the labour force participation rate for a range of countries, often based on labour and household surveys. Table 2.3 outlines data on male and female labour force participation (percentage of working-age people employed or actively looking for employment). According to this data, Cambodia had the highest labour force participation, both total and female, while the lowest labour force participation rate was in Lao PDR. However, changes to the definition of employment and unemployment in 2017 means that the large number of people in Lao PDR who are engaged in own-use production of goods are no longer classified as being in the labour force, whereas in previous definitions and in other countries where this change hasn't been accounted for, these people are still considered part of the labour force. Therefore, the results from Lao PDR are not directly comparable to other countries. In most countries, more than 50% of women participated in the labour force, with the lowest participation for women in Lao PDR, the Philippines and Myanmar. The ILO also compiles data on the percentage share of total informal employment. In Cambodia, Indonesia and Lao PDR, the proportion of informal employment of total employed people is over 80%. In some countries (Malaysia, Taiwan, Republic of Korea and the Philippines), there is no information on the proportion of informal employment.

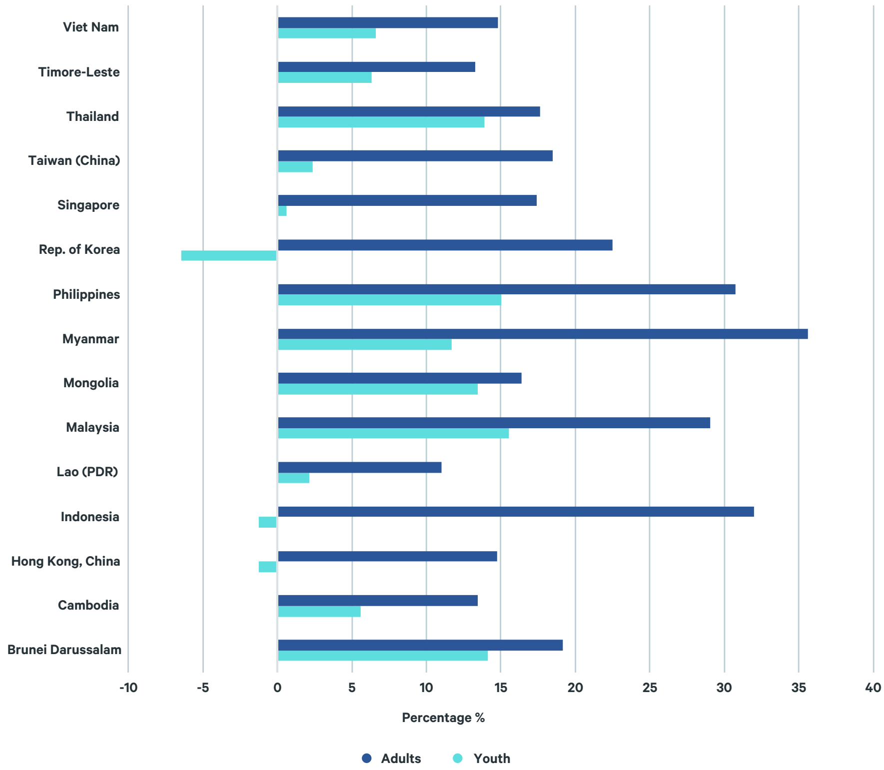
Table 2.3: Labour force participation, youth labour force participation and female labour force participation (%) for most recent years available (International Labour Organization, 2020a) and % of total employment which was informal for the years shown (International Labour Organization, 2020b, 2020c)

Country (Year)	National Youth Labour Force Participation (15-24)	National Adult Labour Force Participation (25+)	Female Adult Labour Force Participation (25+)	Proportion of informal employment in total employment (%)
Brunei Darussalam (2019)	39.8%	62.7%	60.7%	30.9% (2019)
Cambodia (2017)	71.6%	81.4%	79.5%	93.6% (2012)
China		-	-	-
Hong Kong (2019)	40.2%	63.0%	56.5%	-
Indonesia (2020)	47.1%	68.2%	57.2%	80.4% (2019)
Lao PDR (2017)	28.4%	40.8%	40.0%	82.9% (2017)
Macau		-	-	-
Malaysia (2019)	45.8%	68%	62.2%	-
Mongolia (2020)	31.0%	59.6%	57.6%	41.4% (2020)
Myanmar (2019)	45.3%	61.2%	47.9%	79.9% (2019)
Philippines (2019)	34.8%	59.1%	43.4%	-
Republic of Korea (2020)	26.3%	63.5%	56.3%	-
Singapore (2019)	38.3%	67.7%	64.6%	-
Taiwan (Region) (2019)	36.1%	58.8%	53.8 %	-
Thailand (2019)	40.4%	67.5%	63.8%	64.4 % (2018)
Timore-Leste (2016)	39.7%	81.1%	74.3%	71.6% (2013)
Viet Nam (2020)	48.9%	76.1%	65.2%	67% (2020)

Table 2.3 shows the national labour force participation rate for youth and adults. In all countries the proportion of youth engaged in the labour market is lower than that of adults. This may reflect youth still in education or training. The highest youth participation rate was in Cambodia at 71.6%, while in all other countries, the labour force participation rate for youth was less than 50%. Figure 2.1 shows the difference in labour force participation between males and females for adults and youth. In all countries shown, there is a larger difference in labour force participation rate between males and females for adults compared to youth. In the Republic of Korea, Indonesia and Hong Kong there is a larger percentage of employed female youths compared to males, but this is reversed for adults. This may reflect women leaving the workforce when they get married or start a family. In Myanmar, Philippines and Indonesia, there is a 30% difference between the labour force participation rate for females and males, while in all countries there is at least 10% fewer women engaged in the labour market compared to males (Figure 2.1). These figures reflect persistent unequal division of unpaid labour and care work, as well as pay gaps.

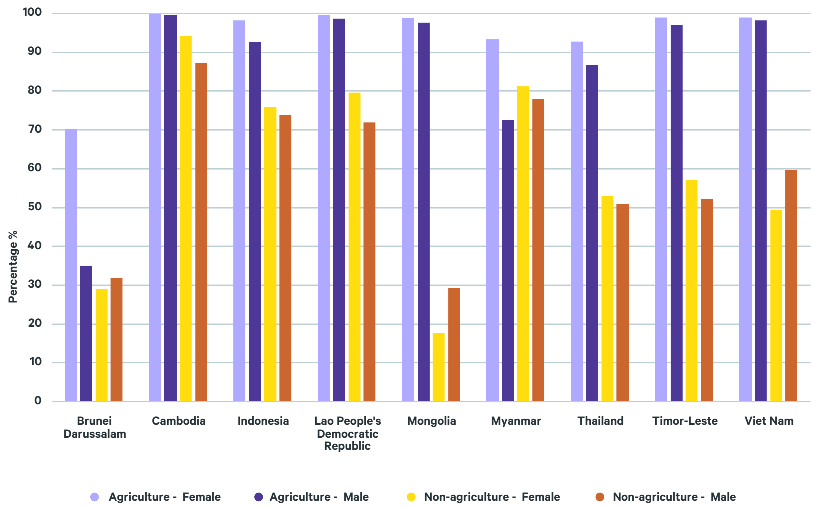
Informal employment covers a wide range of employment and not just employment in the informal sector. This comprises people who, in their main or secondary jobs, work for informal enterprises or for their own final use, contributing family workers or hold informal jobs (not subject to taxation, labour force regulation, social protection or employment benefits). Figure 2.2 shows each country's proportion of total informal employment for agriculture and non-agriculture sectors disaggregated by sex, where data is available. In the agriculture sector, informal employment reaches almost 100% for both males and females in Cambodia, Indonesia, Lao PDR, Timor-Leste and Viet Nam. In Brunei Darussalam, Mongolia and Myanmar, there is a larger proportion of females in informal employment compared to males in the agriculture sector, suggesting women are more likely to be informally employed in this sector. The non-agriculture sector has a smaller proportion of informal employment for all countries. In Brunei Darussalam, Mongolia, Thailand, Timor-Leste and Viet Nam, less than 60% of both males and female total employment is classified as informal.

Figure 2.1: Percentage difference in labour force participation rate between males and females (% rate in males, -% rate in females) for adults (25+) and youth (15-24) (International Labour Organization, 2020b)[1]



Source: International Labour Organization 2020b

Figure 2.2: Proportion of informal employment in total employment (International Labour Organization, 2020c)



Source: International Labour Organization 2020a

1 The labour force participation rate is a measure of the proportion of a country's working-age population that engages actively in the labour market, either by working or looking for work; it provides an indication of the size of the labour supply available to engage in the production of goods and services, relative to the population at working age (ILO, 2020b). This rate may underestimate certain groups of workers, such as those who are working unpaid, such as women performing domestic care work.

Figure 2.3 showcases the percentage split of workers disaggregated by sex according to ILO estimates for 2019 across six aggregated subsectors: agriculture (including forestry and fishing), manufacturing, construction, mining and quarrying (including electricity gas and water supply), business services (trade, transportation, accommodation and food, and business and administrative services), and public services (public administration, community, social and other services and activities). In several countries (Brunei Darussalam, Hong Kong, Republic of Korea, Macau , Malaysia, Singapore and Taiwan), a large majority of the workforce are employed in some form of service industry (business or public services). In Cambodia, Lao PDR and Myanmar, more than one-third of the workforce is employed in the agriculture, forestry and fishing sector.

Figure 2.3: Percentage share of employment in agriculture, manufacturing, mining and quarrying (including utilities), business services and public services, based on ILO modelled estimates for 2019. An explanation of specific activities in each of the broad sectors is described above (International Labour Organization, 2020a).

Source: International Labour Organization 2020a

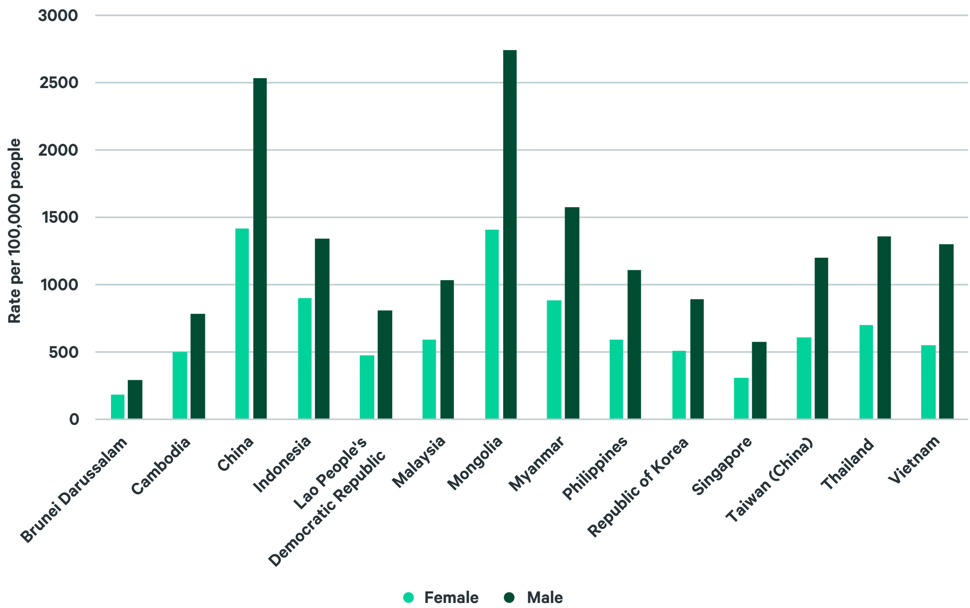
2.2.4 Countries ranked by health impacts (according to GBD data)

Exposure to air pollution contributed to 6.67 million premature deaths in 2019. Of these, about 2.31 million deaths were attributed to household air pollution, 4.14 million to ambient PM pollution and 365 000 to ambient ozone pollution exposure. Occupational exposure to PM, gases and fumes resulted in 524 000 premature deaths, predominantly in South Asia. Here, we show the years of life lost (YLL) due to exposures to these types of pollution for countries and territories in East and Southeast Asia. Years of life lost is a metric which describes the number of years of life that were prevented from being lived due to the different exposure levels (Institute of Health Metrics and Evaluation, 2020a).

a.) Ambient PM exposure

The health impacts of exposure to ambient particulate matter were estimated in a Global Burden of Disease study (2019) (Institute of Health Metrics and Evaluation, 2020b) This study linked concentrations of ambient PM in each country to a relative risk which has been calculated per unit mass of PM for respiratory and cardiovascular disease, lung cancer, total cancers, stroke, diabetes and kidney disease, and respiratory infection. Figure 2.4 presents the YLL for all countries studied, separated by sex. This is based on relative risk per unit of ambient PM, which describes the increased risk from being exposed to increased levels of PM. The overall risk is then calculated from estimated exposure levels and the age- and country-specific baseline mortality rate. The YLL rate per 100 000 population for all countries is higher for males than females, which could be due to assumed increased exposure for males or due to males having a higher baseline mortality rate. The highest average YLL (rate per 100 000 people) due to exposure to ambient air pollution is in Mongolia and China, and the lowest is in Brunei Darussalam and Singapore (Figure 2.4). This correlates with the annual average air quality data and EDGAR emissions data, which show high levels of $PM_{2.5}$ emissions and average concentrations in China, high annual average $PM_{2.5}$ concentrations in Mongolia, low emissions and concentrations in Singapore and a low level of $PM_{2.5}$ emissions in Brunei Darussalam (Tables 2.1 and 2.2).

Figure 2.4: Rate per 100 000 population of the years of life lost (YLLs) due to exposure to ambient particulate matter separated by country and sex (Institute of Health Metrics and Evaluation, 2020a)

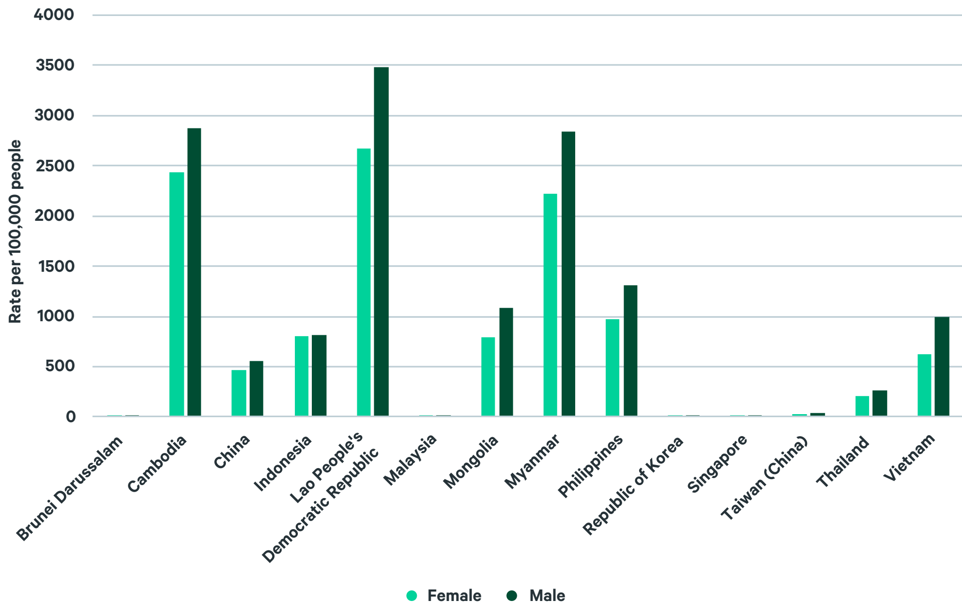


Source: Institute of Health Metrics and Evaluation 2020

b.) Household air pollution

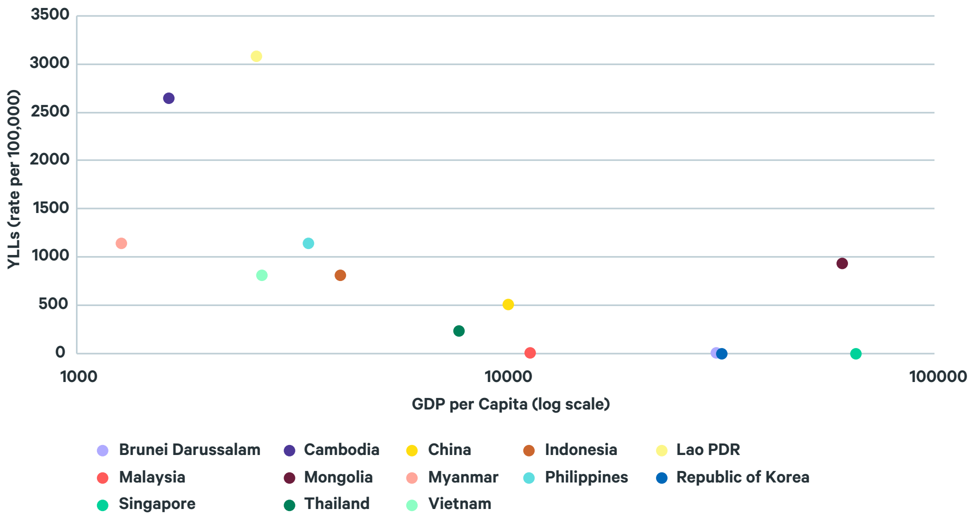
The diseases associated with household air pollution in the GBD study are the same as for ambient PM. There were significantly higher rates of YLLs for Lao PDR, Cambodia and Myanmar compared to the other countries. On the whole, while the rate of YLLs is still higher for males than females, the differences between the results for males and females are smaller than for ambient PM, due to exposure to household air pollution from solid fuels more greatly affecting women and children, as they are often most systematically exposed (see Figure 2.5). However, despite the higher exposure for women, men often have overall worse health or a higher baseline mortality from cardiovascular and respiratory diseases, particularly in countries where a much higher proportion of males smoke tobacco. The largest YLL rate for household air pollution was 3487 per 100 000 people for males in Lao PDR. Given that the highest YLL rate for ambient PM exposure in the countries studied is 2747 per 100 000 people (among males in China), this suggests that in several countries, the health impact of household air pollution is broadly greater than that of ambient PM exposure. However, for ambient air pollution for males, there was a rate higher than 1000 per 100,000 people in eight of the14 countries, compared to five of the countries countries for household air pollution. This suggests that ambient PM pollution is more of a widespread problem across the countries examined. The largest health impacts of household air pollution from solid fuels occurred in the countries with the lowest GDP per capita out of all countries (Figure 2.6).

Figure 2.5: Rate per 100,000 population of the years of life lost (YLLs) due to exposure to household air pollution from solid fuels



Source: IHME (Institute of Health Metrics and Evaluation) 2020

Figure 2.6: Relationship between years of life lost (rate per 100 000 population) due to household air pollution from solid fuels and GDP per capita (World Bank, 2019)



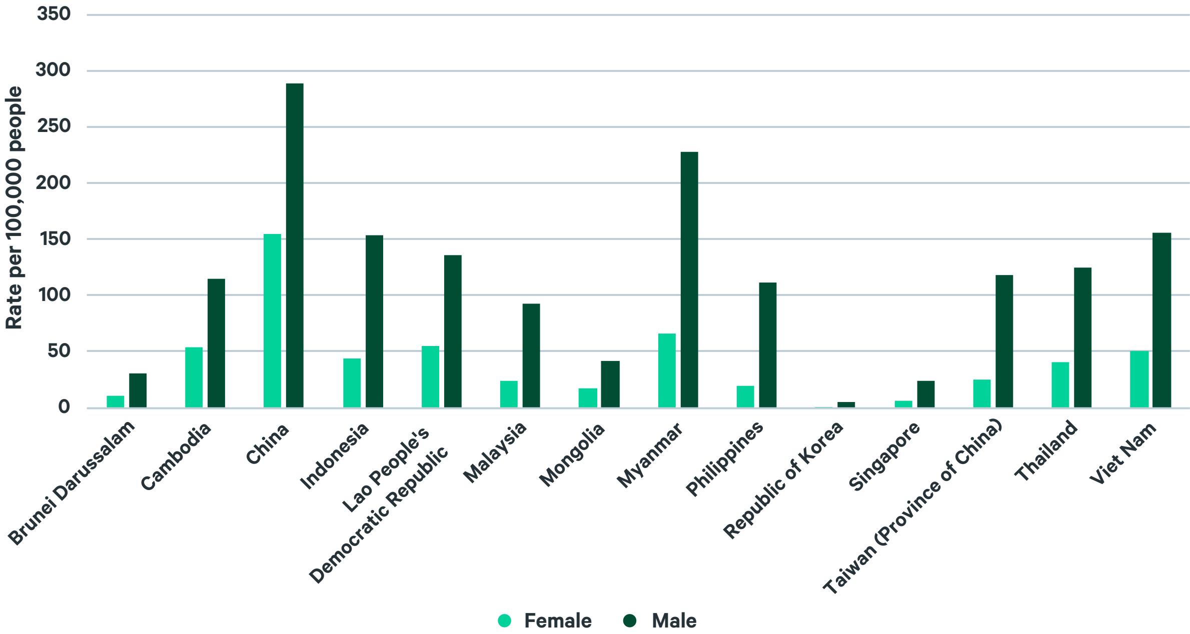
Source: World Bank 2019 and IHME 2020

c.) Occupational exposure

In the GBD 2019 study, the only health burden of occupational exposure to PM, gases and fumes considered is respiratory disease. This contrasts with the impacts of ambient PM and household air pollution exposure where the health burden is linked to a variety of diseases and infections including cancers, cardiovascular disease and diabetes, and neonatal and prenatal disorders. According to the GBD data, the health burden of occupational exposure is much lower than that for ambient PM and household air pollution exposure – but that may be attributed to the scant ailments associated with occupational exposure in this study, or limited research on the health effects in many countries, compared to the impact of ambient PM and household air pollution exposure. Consequently, in order to fully understand the impact of occupational exposure, more studies need to be done in this area.

The highest rate of YLLs due to occupational exposure is 300 per 100 000 people for males in China (see Figure 2.7). There is also a large difference between the rates for women and men, with the impact on females more than 50% lower than for males in all countries. This may be due to the lower participation of women (Table 2.1) in formal employment, as the calculation of exposure used in the GBD study is based on ILO data. In addition, males suffer a higher health burden in most countries generally and are therefore more susceptible to the effects of exposure to air pollution. Furthermore, the occupational exposure calculations do not consider exposure from informal work, which remains a major gap.

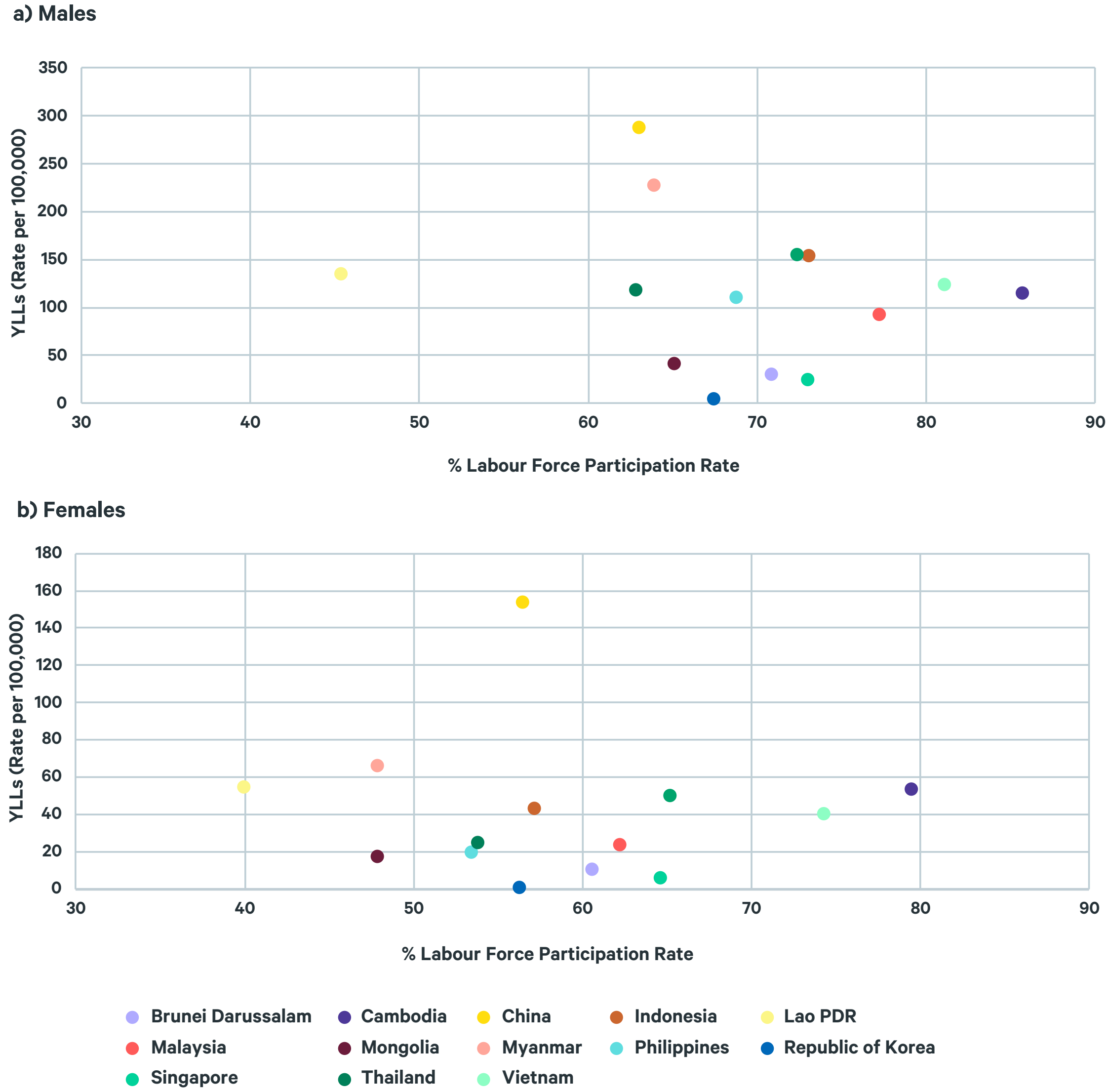
Figure 2.7: Rate per 100 000 population of the years of life lost (YLLs) due to occupational exposure to particulate matter, gases and fumes



Source: IHME (Institute of Health Metrics and Evaluation) 2020

Comparing the YLLs due to occupational exposure to PM, gases and fumes (Figure 2.7) with the share of employment in different economic activities (Figure 2.3), countries with the lowest health impacts due to occupational exposure (Brunei Darussalam, Mongolia, Republic of Korea and Singapore) are also those with a high percentage of employment in the services sector (either business or public services) (See Figure 2.8.). In contrast, those with the highest health impacts due to occupational exposure (China, Myanmar, Indonesia, Lao PDR and Viet Nam) also have a large proportion of employment in the agricultural and manufacturing sectors. According to the EDGAR Emissions data (Annex 2.1), the manufacturing, industries and construction sector is in the top four sectors in terms of $PM_{2.5}$ emissions for most countries, indicating it is a large source sector for air pollutant emissions in most countries. Similarly, in several Southeast Asian countries, small-scale biomass burning is one of the largest contributors to total $PM_{2.5}$ emissions, potentially highlighting the high health impacts for employees working in agricultural areas.

Figure 2.8: Relationship between YLL due to occupational exposure to PM, gases and fumes and labour force participation rate for adults (25+) for a) males and b) females



Source: International Labour Organization (ILO) 2020b and IHME 2020

Comparing the health impacts for males and females, the largest difference in health impacts is found in Indonesia, Myanmar and Viet Nam, where the rate of YLLs due to occupational exposure for males is more than three times that of females. In Indonesia and Myanmar, there is a large (more than 30%) gap between male and female labour force participation, which may be a reason for the large difference in health impacts. However, in Viet Nam, the gap between male and female labour force participation rate is much lower (15%). A more detailed analysis of literature focusing on air pollution exposure for specific subgroups and occupations is presented in the following chapters.

Chapter 3: Social dimensions of air pollution in the world of work

By Jenny Yi-Chen Han

This chapter seeks to answer the following question: "What is the state of knowledge on the social dimensions of air pollution in the world of work?" This question examines the distribution of air pollution impacts on employment and workforce, characterized by sex, age, ability, ethnicity, race and wealth. Employment and workforce include paid and self-employment, short-term, part-time and seasonal employment. In this context, "social dimension" refers broadly to the ways that sociodemographic factors such as gender, age, ethnicity, economic and occupational statuses create differentiated exposures to and impacts of air pollution. This focus shifts attention away from solely the physical health impacts of air pollution to focus on how air pollution affects worker groups differently and how it may exacerbate existing inequalities within the work world.

This chapter is not confined to a particular geographical boundary, as it is helpful to broadly understand the worldwide state of knowledge on this subject matter in order to get an idea of how the topic of air pollution, labour and its social dimensions have been approached in general. Through this broad overview, the current studies globally can also inform how this topic can be explored in the Southeast and East Asian region.

3.1 Methodology

To answer our question, we conducted an exploratory literature review that mapped out thematic topics and their prevalence in the literature on the social dimensions of air pollution in workspaces globally. Although a full systematic review was not possible due to time and resource constraints, this exploratory literature review developed a simplified review process by adopting principles from systematic review and mapping methodologies (Haddaway et al., 2015). This is done to carry out a comprehensive review that minimizes bias and maximizes transparency. Due to time and resource constraints, the study team decided to narrow the search to only one academic database: Scopus. See detailed method, screening process and limitations in Annex 3.

3.2 Findings

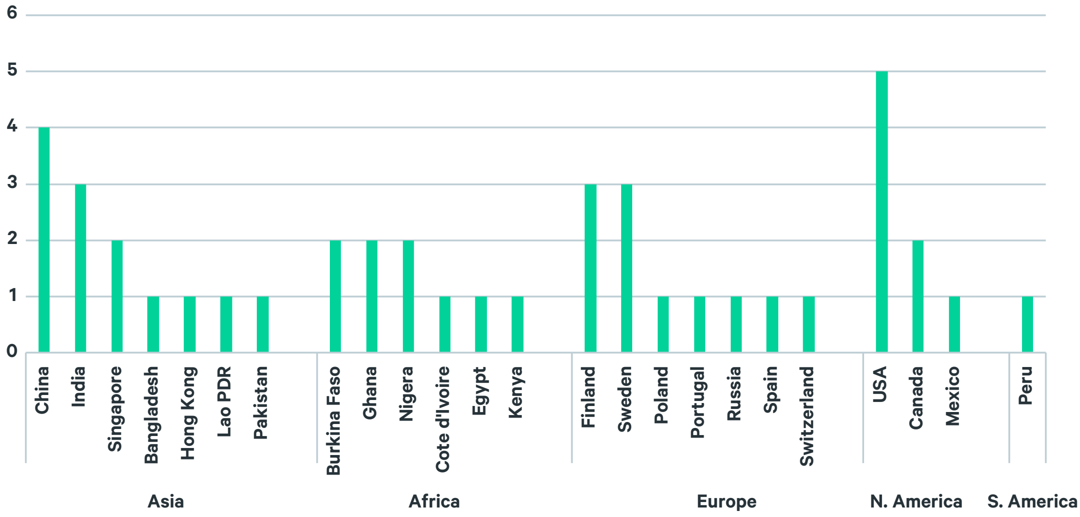
3.2.1 Overview of thematic focus and geographic distribution

Scopus yielded 1189 articles, with 1076 articles remaining after excluding duplicates. From this, we excluded 908 articles after title screening and another 46 after abstract screening for relevance. This left a total of 122 articles to undergo full text screening. Of these, 17 articles could not be found or retrieved online for various reasons and were excluded from the pool. Ultimately, the full text screening resulted in the inclusion of 50 articles that explicitly discussed air pollution's impact on social dimensions in the world of work and labour (see Figure 3.1).

Overall, 19 studies are based in European countries and North America. In comparison, nine articles focused on an African country and 13 articles looked at Asian countries. Within those, four focused on Mainland China (and one on Hong Kong). We could not find studies focusing on the Pacific countries. Studies that mentioned multiple countries or with a regional focus (e.g. Sub-Saharan Africa) were not included in the count.

The review revealed that the **impacts of air pollution are largely framed by a public health and medical perspective, rather than by the day-to-day experiences of exposed groups**. Almost all of the assessed articles used quantitative methods in the studies, with only two articles using qualitative methods (Becerra et al., 2020; García-Mainar et al., 2015) and three articles using mixed methods (Dianati et al., 2019; Sana et al., 2017; Vaktskjold et al., 2008). While quantitative studies provided measurements on specific impacts and outcomes (e.g. health hazards) of

Figure 3.1. Count of studies by region and country



air pollution, qualitative and mixed methods provided insights into workers' perceptions and experiences with air pollution.

Based on the retrieved articles, **this review shows that there is more data on the impacts of air pollution on the formal labour force than the informal, particularly within urban settings.** Of the 50 total publications, 24 articles look at the impacts of air pollution on workers in the formal labour force, with 19 articles exploring the informal labour force (including unpaid care labour and informal paid labour), and seven articles discussing both forms of labour. Within these categories, studies on informal paid labour constitutes the lowest number of articles at six. This may also suggest a gender imbalance in data, because though more total men than women in the world are informally employed, the percentage of women workers in informal employment in developing countries is often higher than the percentage of men workers, at 92% versus 87% (Bonnet et al., 2019, p. 5). Thus, depending on the country in focus, substantial gender dimensions may be overlooked due to the formal work data availability bias.

In terms of the type of air pollution studied, most articles looked at indoor air pollution (31) compared to outdoor air pollution (11), with eight articles examining both. In addition, most of the studies looked at the impacts of air pollution in the urban environment rather than rural, with only 14% of the articles focusing explicitly on rural areas. Within this cohort of studies looking at rural areas, all but one study (Flunker et al., 2017) are on informal or domestic labour. Within the studies that highlighted indoor air pollution in an urban setting, a few (4) discussed the phenomenon of sick building syndrome[2] (Abdel-Hamid et al., 2013; Gomzi & Bobić, 2009; Nezis et al., 2019; Thach et al., 2019). In addition to physical health impacts, many of the studies on office workers also mentioned the psychological impacts of air pollution on workers as well, which may influence other factors such as productivity (Abdel-Hamid et al., 2013; García-Mainar et al., 2015; McDonald et al., 1993; Mendell, 1993; Nezis et al., 2019; Runeson et al., 2003; Soriano et al., 2018; Zhu et al., 2020). Interestingly, psychological impacts were only mentioned in studies on office workers.

2 Sick building syndrome (SBS) is a condition in which building occupants experience illness or disease that may be linked to elements of the building in which they reside or work. However, causes of SBS are often unidentified.

Figure 3.2. Air pollution's effects on labour named in literature review

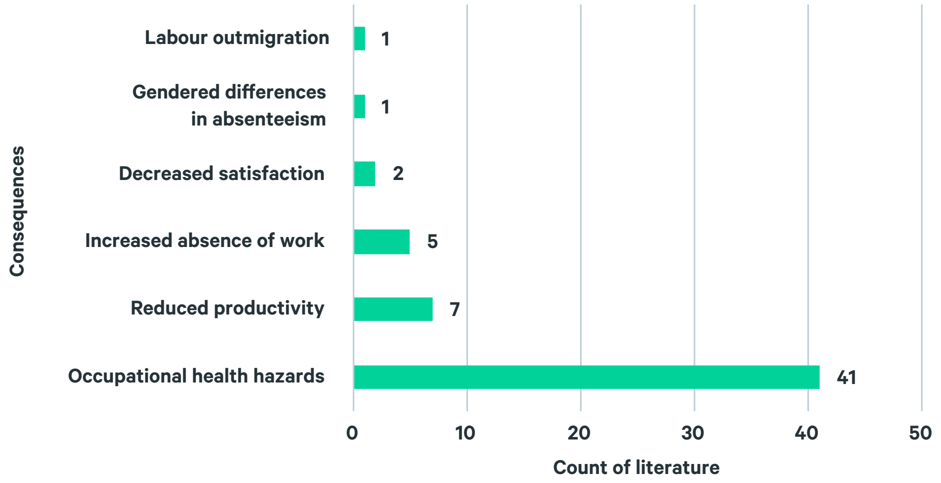
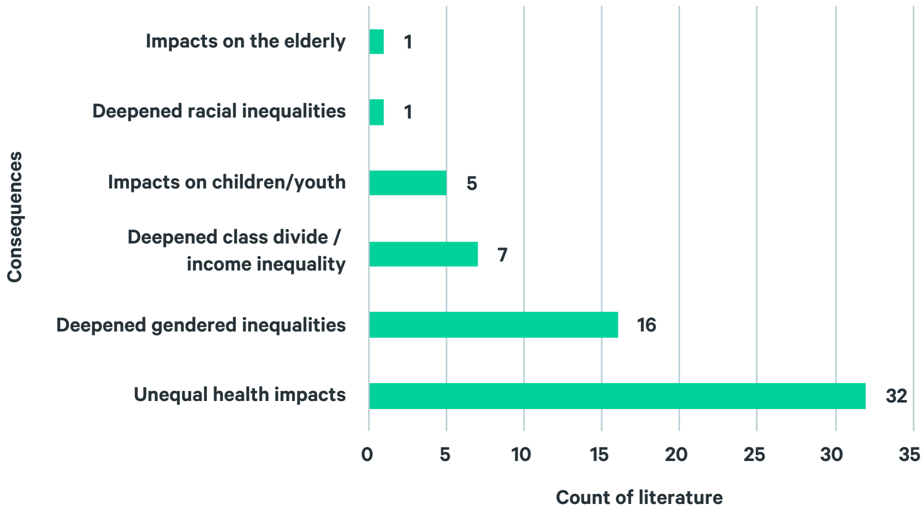


Figure 3.3. Air pollution's effects on various social dimensions named in the literature



Across all the assessed articles, **occupational health hazards are by far the most commonly addressed consequence air pollution has on labour**, with 41 out of the 50 assessed articles focusing on this issue (see Figures 3.2 and 3.3). Several articles also mentioned decreased productivity as a consequence of air pollution in the workspace, which are associated with health hazards and increased work absence. One study focusing on sick building syndrome (Abdel-Hamid et al., 2013) also mentioned decreased satisfaction in the workplace correlating with reduced productivity.

The articles show evidence that **air pollution has differentiated impacts among groups particularly along the line of gender, age, race, and class**. While 28 of the 50 assessed articles mentioned gendered aspects of air pollution's impact, the majority of the articles do not provide in-depth analysis of gendered dimensions to air pollution, but rather mention gender as one of many factors. Even so, the articles do not explicitly engage in an intersectional analysis of how gendered exposures are affected by other social aspects – but they do mention that factors such as geography play an important role in mediating gendered exposures to air pollution. According to the retrieved articles, women in rural areas may be more exposed to outdoor air pollution than women in urban areas (Akinbami & Momodu, 2013; Gu et al., 2020). For example, Gu et al.'s (2020) study on air pollution's effects on female labour supply in China found that while the female labor participation is highly susceptible to air pollution in rural areas (i.e., air pollution impacts the ability of women laborers to work), the effect is not significant for female labour in urban areas. This may be because in the studied areas, more women in urban settings are likely to be working in indoor settings (e.g., offices and factories) compared to women in rural settings. Only one article mentioned the differentiated impact of air pollution on men based on their overrepresentation in certain sectors (C. Wang et al., 2020). At the same time, most of the articles on indoor air pollution and domestic labor focus on the impacts of biomass fuels and indoor cookstoves emissions on women. This was described in both the urban context (Bede-Ojimadu & Orisakwe, 2020; Dianati et al., 2019; Jedrychowski et al., 1990; Lakshmi et al., 2013; Mengersen et al., 2011; Mortimer et al., 2012; Sana et al., 2019; Stabridis & van Gameren, 2018; Weber et al., 2020; Wei See et al., 2006) and in the rural context (Akinbami & Momodu, 2013; Bede-Ojimadu & Orisakwe, 2020; Lakshmi et al., 2013; Mengersen et al., 2011; Mortimer et al., 2012; Pial et al., 2020; Sarmah & Bhagawati, 2014; Stabridis & van Gameren, 2018; Tigala et al., 2018; Van Vliet et al., 2019).

Given the extensive existing literature on the relationship between race and exposure to pollution (particularly within environmental justice scholarship), it was surprising that race is only mentioned explicitly in one of the articles reviewed here (Flunker et al., 2017). One reason for this may be that despite the wealth of literature on race and unequal exposures to air pollution, more studies have focused on residential exposure rather than occupational exposure. Another possible explanation for the lack of literature retrieved may be due to the narrow terms in our search string that eliminated potential articles on the topic.

3.2.2 Unequal impacts of air pollution within the world of work

a. Invisibility of informal worker groups

As mentioned previously, most of the assessed studies focused on the formal workforce, where data on various aspects of labour (workers' health, absence rate, satisfaction level) are more easily collected. In comparison, **fewer studies focus on informal worker's exposure to air pollution**. Akinbami and Momodu's (2013) study explores the health risks faced by female entrepreneurs involved in food processing in rural Nigeria, who are exposed to air pollution from burning solid fuels. Despite the health hazards, there is a lack of regulatory frameworks to monitor ambient air quality. In particular, no policies specifically target the needs of rural women and children, who are most vulnerable to air pollution. Sly et al. (2019) points out that in countries such as India and Bangladesh, children constitute a large section of the informal labour workforce and are often engaged in occupations with high exposures to hazardous pollutants (e.g., heavy metals), such as garbage collection and disposal (e.g., electronic waste recycling). While not discussed in the study, the gendered implications of child labour and occupational health hazards are inferred. Because mothers tend to be primary caregivers in the home, sick children will subsequently increase the domestic labour burden of women.

b. Domestic work and caregiving labour

As demonstrated by existing scholarship and confirmed by the literature reviewed here, exposure to household air pollution disproportionately affects women and children due to gendered norms around household work (Aragón et al., 2017; Mengersen et al., 2011; Mortimer et al., 2012; Sana et al., 2019; Stabridis & van Gameren, 2018; Tigala et al., 2018).

Mengersen et al. (2011, p. 1378) confirms the role of indoor air pollution on women and children's health in Lao PDR, concluding that that various symptoms of respiratory illness in women and young children aged 1–4 years were positively related to indoor exposures to activities such as cooking, dusting, and drying clothes inside. Furthermore, Mortimer et al. (2012), Tigala et al. (2018) and Mengersen et al. (2011) stress the link between poverty and exposure as a result of factors such as fuel choice and poor housing structures. In addition to the indirect economic impacts of bad health, the use of biomass fuels in rural areas can further exacerbate poverty because it is time consuming to collect fuel supply, reducing the amount of available time for paid labour activities outside the household (Mortimer et al., 2012; Stabridis & van Gameren, 2018). For those who have to purchase their fuel supply, it can also be financially burdensome as well, and leaves less available resources for other necessities such as food, education and healthcare (Mortimer et al., 2012). Additionally, when air pollution impacts the elderly and/or children, the women's burden also tends to increase because of their domestic caretaking roles. For example, Aragon et al.'s (2017) study found that the "effect of moderate pollution levels on hours worked is concentrated among households with susceptible dependents, i.e., small children and elderly adults" (295). This suggests that those who are responsible for the care of dependents, who in many contexts are disproportionately women, suffer the loss of income-generating work.

c. Hierarchies and inequality in air pollution exposures within informal workspaces

While gender is a key dimension of analysis, studies of gender and workers' exposure to air pollution tend to be biased towards women and their presumptive gendered role, while overlooking men and their gendered exposures. For example, the body of literature on cookstoves and domestic fuel burning (i.e., informal and domestic labour) has largely been focused on women's unequal exposure. However, according to Figure 2.6 from Section 2.2.4., men seem to suffer more years of life lost due to occupational exposures to PM, gases, and fumes. This statistic points to the fact that men, depending on occupational type, are equally, if not more, susceptible to air pollution impacts – yet this perspective is not well captured in existing literature on gender and air pollution. Of the literature retrieved from the search, Wang et al.'s (2020) study touches on this theme, pointing out that men are unequally exposed to air pollution due to differences in labour composition in various occupations. For example, air pollution disproportionally affects sectors with a majority of male and lower-educated workers (e.g., energy-related industries) and will have the least impact on sectors with a higher representation of female and higher-educated workers (e.g., the public administration sector) (ibid). This finding underscores the intersectional nature of air pollution impact – while gender can be a key factor in determining air pollution exposure among workers based on the gendered composition of different sectors, education levels (and in extension, social class and status) intersect with gender in determining exposure levels.

In addition**, gendered labour compositions can vary across countries and cultures, and are often highly intertwined with socioeconomic factors.** For example, Brender et al.'s (2008, p. 834) study revealed that women in production occupations, such as factories, are "twice as likely to reside near these facilities than women in management/professional occupations and more likely to reside near such facilities than other occupational groups." Furthermore, a few studies highlight socioeconomic status as one of the key determinants of unequal air pollution health impacts (Akinbami & Momodu, 2013; Ali et al., 2017; Becerra et al., 2020; Lakshmi et al., 2013; Tigala et al., 2018; C. Wang et al., 2020). This is largely due to the type of occupation held, lack of preventative measures (e.g., protective equipment and policies), and sometimes lack of awareness. For example, a study (Ali et al., 2017, p. 1337) in Pakistan on air pollution's effects on roadside workers reveal that the most occupationally exposed individuals tend to have "low educational level, increased duration of exposure, and more importantly avoidance of preventive measures. ...[Furthermore], the health care facilities in Pakistan for the low-income occupational groups do not meet the international standards." In addition, the study also points out that there tends to be low awareness about precautionary and preventive measures against air pollution across the studied occupational groups in Pakistan (ibid).

Despite the overarching influence of socioeconomic class on exposures to air pollution, the class dimension is nuanced and internal power relationships within a group also play a role in unequal exposures to air pollution. In other words, internal hierarchy within a sector or workplace also influences who does what type of tasks, influencing unequal exposure to air pollution. In Becerra et al.'s (2020, p. 102) study in Abidjan, Cote d'Ivoire, on workers' exposure to air pollution across different informal occupations, the authors reveal that occupational status within each group plays a role in the workers' exposure levels to air pollution. In other words, relationships among workers within a sector mirror existing social inequalities. According to the study, dimensions such as gender- and age-related hierarchies play a part in workers' pollution exposure, and workers "holding the highest occupational statuses in their sector shifted the risk on to the workers at the bottom of the hierarchy by removing themselves from the most exposed tasks." Similarly, in Sana et al.'s (2017) study on air pollution and artisanal gold mining, the finding demonstrated that factors such as economic status and other social dimensions (e.g. gender, educational gaps, differences in tasks and level of seniority) influence gold miners' exposure to air pollution.

While not discussed extensively in the assessed literature, some articles mentioned the ways age-related factors can influence workers' sensitivity or exposure to air pollution (Becerra et al., 2020; Gu et al., 2020; Jedrychowski et al., 1990; Sana et al., 2017). Besides impact on physical health, age-related hierarchies are also cited as a factor that creates inequality in workers' exposure level to pollution (Becerra et al., 2020), as discussed previously.

3.3 Conclusion

This chapter aims to map out thematic topics and their prevalence in the literature on the social dimensions of air pollution in workspaces globally. It specifically examines the disproportionate impacts of air pollution on employment and workforce, characterized by sex, age, ability, ethnicity, race and economic status. The literature review adopted systematic review and mapping methodologies to carry out a comprehensive review that seeks to minimize bias and maximize transparency. The review highlights four main findings. Firstly, the impacts of air pollution are largely framed by a public health and medical perspective, rather than by the day-to-day experiences of exposed groups. Secondly, research on the impacts of air pollution and employment mainly focus on the formal labour force, while the informal labour force remains largely underexamined, particularly within urban settings. Thirdly, studies of gender and workers' exposure to air pollution tend to be biased towards women and their presumptive gendered role, while overlooking men and ways in which gender identity intersecting with socioeconomic factors determine exposures. Lastly, hierarchies within a sector or workplace influenced by gender, social class and other factors also result in unequal exposures to air pollution.

While this review focuses on exploring the social impacts of air pollution, social impacts cannot be divorced from health outcomes, as they are closely interlinked. With this in mind, Chapter 4 will examine the health impacts of air pollution, with specific focus on East and Southeast Asia.

Chapter 4: Vulnerability, differential impacts and occupational exposure

By Charrlotte Adelina and Jaee Nikam

Having reviewed the social impacts from a global perspective, this chapter of the report provides an overview of the literature on the health impacts in workers in East and Southeast Asia. Some workers – such as workers in polluting industries, outdoor workers or domestic workers exposed to cooking fumes – are at greater risk depending on the nature of their work, length of exposure, personal risk factors, and health protections afforded at work. Therefore, they may be more vulnerable to air pollution's health risks. This chapter of the report presents key findings from an evidence-mapping exercise on occupational health impacts of air pollution in East and Southeast Asia specifically. The following sections are organized as follows: the first section describes the methodology adopted for the systematic evidence review, followed by sections outlining the key findings from the evidence and knowledge gaps.

4.1 Methodology

4.1.1 Question formulation

The literature review synthesizes health impacts of air pollution for different groups of workers in East and Southeast Asia. We adopted a systematic evidence review methodology, as outlined in Capter 1.2. The following table presents the different elements covered by the search string using a population, exposure, comparator and outcome (PECO) approach to question formulation.

Table 4.1: PECO question formulated for evidence review of occupational health impacts

Population	Workers in East and Southeast Asia	Includes formal, informal occupations and domestic work such as cooking in households. Work commuters was also included, as it is as a main contributor to health risks of working population.
Exposure	Air pollution	Includes all air pollutants, mainly sulfur dioxide (SO_2), nitrous oxide (NO_2), ozone (O_3), $PM_{2.5}$, PM_{10}, Polycyclic aromatic hydrocarbons (PAH) and volatile organic compounds (VOC).
Comparator	Differential impacts on sub-groups of workers	Includes unequal impacts for population based on age, gender, class, ethnicity, race and disability.
Outcome	Health impacts	Includes conditions such as mortality, heart or cardiovascular disease, strokes, lung cancer and damage to immune, neurological, reproductive and respiratory systems.

A single researcher conducted the evidence mapping exercise with review from the research team. A search string (Annex 4.1.1) was developed and used for identifying matches based on titles, abstracts and keywords of journal articles in Scopus database (access provided by Chulalongkorn University library).

4.1.2 Screening

The search yielded 939 results, of which 909 articles were written in English. These articles were then screened in Rayyan software to only include articles relating to occupational health in East and Southeast Asia and reliable sources published in scientific journals. The first round of screening selected articles based on title and abstract. Articles that studied Covid transmission and associated health impacts in air polluted areas were excluded. Articles that do not explicitly delineate human health impacts of air pollution but are studies that assess metrics for measuring the health impacts of air pollution or are controlled laboratory experiments were also eliminated. In addition, other background reviews and systematic reviews that summarize overall health impacts were excluded.

After screening all results, 59 relevant papers remained. We downloaded full texts of these articles, out of which seven articles were not accessible. Based on another round of screening based on full texts, seven more articles were found to not measure the health impact of air pollution exposure. We extensively reviewed the full texts to synthesize key evidence regarding bibliographic information, details of the population, pollution exposure, health impacts and identified solutions, in a codebook, which systematically categorizes the contents of the reviewed literature. The systematic map presented thus summarizes a review of 45 relevant articles relating to the occupational health impacts of air pollution in East and Southeast Asia.

4.1.3 Limitation of the study

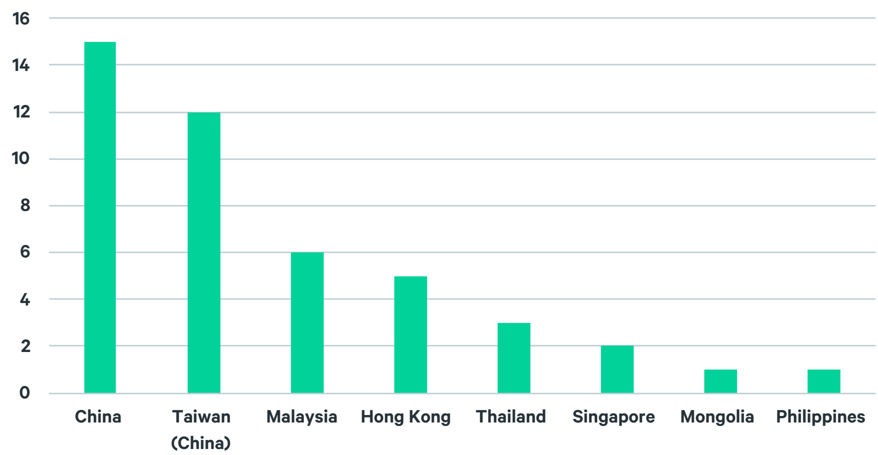
A limitation of the study is that the search string was narrowed down to render the project feasible under the given time constraints and capacities. A second limitation is that, although some of the literature pointed to zero results (no impact of pollutant exposure on health), the report does not outline these set of results in order to report a concise and relevant set of findings.

4.2 Findings

4.2.1 Overview of study setting

All articles reviewed were published in a journal. Fifteen journal articles were published between 2000 and 2011, which increased to 30 articles between the years 2011 and 2021, indicating an increased research interest in the topic. The most common methodology used by researchers to assess health impacts of air pollution included a combination of a survey, pollutant measurement and health assessment (19 articles). The survey is employed to assess basic information on participants, health risks, symptoms, length of exposure and personal dietary habits. Pollution measurements are carried out either through indoor pollutant measurements, worker exposure assessments or ambient data measures. Though health impact assessment from chemical analysis of biomarkers is most common, other health tests such as spirometry, analysis of health or mortality records, or self-reported health symptoms of respondents were also used. Only one study relied on modelling of city-level pollution and mortality inventory data to present their results. All studies were quantitative.

Figure 4.1: Count of studies by country

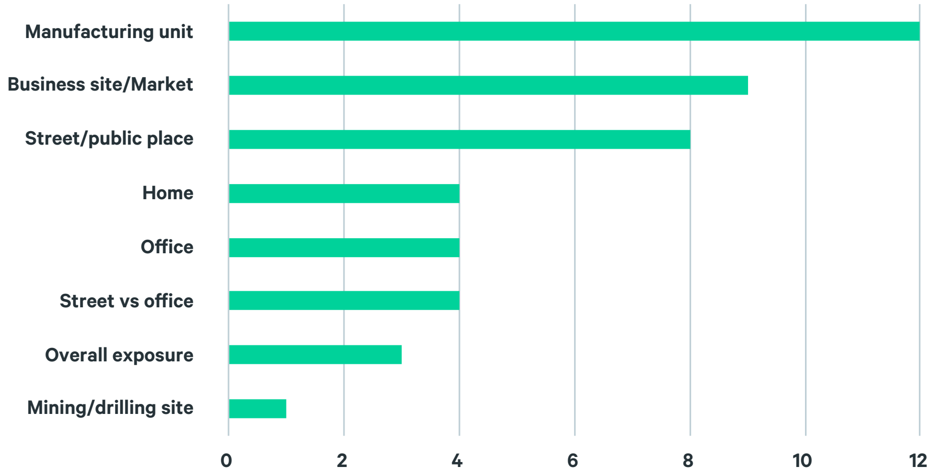


Sixty percent of the set of results are from China and Taiwan (see Figure 4.1). There were no results from Vietnam, Lao PDR, Brunei, Indonesia, Myanmar, Macau, and the Republic of Korea. This indicates lesser research on occupational health impacts of air pollution in these countries, but could also be attributed to the location-agnostic search string used for the evidence review. Thirty-three articles cover air pollution impacts in an urban setting, one study is based in a semi-urban setting, two on both urban and rural areas, and only one specifically pertains to a rural area. Of those studies located in urban settings, research sites are often worksites in primary cities (a country or metropolitan area's largest cities) like Guangzhou, Beijing, Kuala Lumpur, Manila and Taipei.

4.2.3 Context of Occupational Exposure

Forty of the 45 articles studied workers who were exposed to pollution resulting from conducting paid work activities (see Figure 4.2). Three studies illustrated health impacts of domestic work and two discussed differentiated impact in lower-class workers due to overall exposure to air pollution. More studies investigated indoor (24) than outdoor (12) pollution.

Figure 4.2: Count of articles by exposure site



The most frequently studied pollution exposure setting among the articles is manufacturing units such as welding units, foundries, PVC production sites, or diesel engine production sites (12). Workers in business sites (featured in nine articles) included those working in dental clinics, restaurant kitchens and hair salons. Outdoor workers such as toll station workers and street vendors exposed in public spaces were also reviewed, traffic police workers being the most studied group. Four studies highlighted work performed at home, whether it was domestic work or other roles such as dental work or electronic waste dismantling (Hu et al., 2006; Puangprasert & Prueksasit, 2019) carried out in domestic spaces. Four studies also compared the health impacts of air pollution exposure in office (as a control group) versus highly exposed outdoor workers such as truck drivers or traffic policemen. Compared to studies in the US and Europe, research in Asia is comparatively less focused on workers who perform jobs at or respond to mining and drilling sites.

When looking at studies by the source of pollution, road transportation is the most-studied source (14 articles), followed by manufacturing industries and construction (seven articles). Of the 37 studies that focus on workers generally, 23 of those highlight workers in formal enterprises. Only five of those studies relate to exposure occurring at informal places of employment. We note that 15 of the studies did not explicitly mention the nature of job formality.

4.2.4 Overview of health impacts of air pollution

This section summarizes the existing evidence on the effects of air pollution on health outcomes such as increased carcinogenic and mortality risks and impacts on respiratory, cardiovascular, neurological and reproductive systems.

Increased carcinogenic risks: Prolonged exposure to air pollution can pose cancer risks in workers. Carcinogenic risks through oxidative damage increases with exposure to volatile organic compounds (VOCs), which are organic chemicals emitted in gaseous form from liquids and toxic metal fumes found in spray paints for spray painters (Lin et al., 2019); industrial emissions, dust from the Earth's crust and coal combustion for workers in harbor areas (B. Liu et al., 2021); elemental carbon for workers producing and packaging carbon black (Dai et al., 2016), and polycyclic aromatic hydrocarbon (PAHs), which are chemical compounds containing carbon and hydrogen naturally found in coal, for foundry workers (H.-H. Liu et al., 2010). Oxidative DNA damage, stress or inflammation risks have been reported in factory workers exposed to exhaust from diesel engines (Duan et al., 2016), traffic conductors (Hallare et al., 2009; Huang et al., 2012; Tan et al., 2017), gas station attendants (Hallare et al., 2009), highway toll-station workers (Y.-J. Zhao et al., 2018), hair salon workers (Ma et al., 2010) and shipyard welders (Lai et al., 2020). Indoor pollution exposure to ozone and $PM_{2.5}$ due to printing and photocopying activities in offices can also pose carcinogenic risks (Othman et al., 2020). Those exposed to toxic metal fumes are especially at risk, as seen in the case of prolonged exposure to cadmium and nickel among electronic waste dismantling workers with increased cancer risks (Puangprasert & Prueksasit, 2019). PAHs in cooking oil fumes cause cancer risks for restaurant kitchen workers (J. Wang et al., 2011) and the risk increases while using cooking methods like deep frying or stir frying (Wei See et al., 2006) or with reused frying oils (Ke et al., 2016). In residential kitchens with poor ventilation and prolonged exposure, cancer and other health risks are often posed to women (Yu et al., 2015).

Impact on lung function: Deposition of ultrafine particles can affect lung function and cause a range of pulmonary diseases. Lung function decline due to pollution was reported in printing room workers (Lyu et al., 2021), non-air-conditioned bus drivers (Jones et al., 2006), factory workers who produced and ingested milk powder (Sripaiboonkij et al., 2008), restaurant workers using gas stoves (Wong et al., 2011) and dental workers (Hu et al., 2006). Occupational exposure to industrial heat and wood dust was significantly associated with nasopharyngeal carcinoma (Armstrong et al., 2000). Lung function was lower in roadside vendors when compared to indoor workers (Jones et al., 2008). An exceeding amount of respiratory suspended particulates were found in newspaper and magazine vendors, which can linger in the respiratory system and cause a number of diseases (Ng & Lam, 2001). Sulfur dioxide (SO_2) from biomass fuel consumption can lead to chronic obstructive pulmonary disease (COPD) for women cooking in rural areas (S. Liu et al., 2007).

Impact on upper respiratory systems: Excess VOCs in dental clinics can cause irritation in the upper respiratory systems and fine particles entering the nervous system have been found to cause headaches, nausea and dizziness (Hong et al., 2015). Several studies found that workers in office buildings with poor indoor quality suffered from headache, migraine, fatigue, difficulty in concentration, eye irritation, nasal stuffiness, cough and difficulty in breathing (Syazwan et al., 2013; Zamani et al., 2013). Skin and eye irritation due to carbon exposure, and sore throat and coughing due to toluene exposure were found in factory workers packing carbon black (Dai et al., 2016). Exposure to occupational phthalates from PVC production led to oxidative stress, headache, irritation and decreased kidney function (W. Wang et al., 2015). Traffic police reported coughing due to continuous exposure to $PM_{2.5}$ (Jamil et al., 2019).

Increased mortality risks: Mortality risks were significantly associated with particulate matter exposure in office environments where high levels of energy are consumed throughout the building's life cycle (Othman et al., 2018) and from heavy use of printers in printing rooms (Lyu et al., 2021). In a study that analyzed mortality records based on socio-economic status, prolonged exposure to $PM_{2.5}$ was found to pose increased cardiovascular and respiratory risks for outdoor workers (J. Wang et al., 2017). Similarly, overall exposure to PM_{10}, SO_2, NO_2, and O_3 increased mortality risks for blue collar workers more than white collar workers (Ou et al., 2008), due to compounding exposure to air pollution at the workplace and their higher likelihood of living in more polluted areas.

Other health risks: Links between air pollution and other health risks such as cardiovascular and renal (kidney) risks are also established. $PM_{2.5}$ exposure led to cardiovascular disease for workers packing carbon black (Dai et al., 2016), increased blood pressure for truck drivers (Baccarelli et al., 2011) and decreased heart rate variability for hair salon workers (Ma et al., 2010). PM_{10} was found to lead to hypertension in both air-conditioned and non-air-conditioned bus drivers (Jones et al., 2006). PM_1 is linked to increased blood pressure in printer room workers (Lyu et al., 2021), while also leading to arterial stiffness in mail carriers (C.-F. Wu et al., 2010). Exposure to PM_{10}, SO_2 and NO_2 in policemen was linked to increased risk of renal diseases compared to the general population (Tang et al., 2021). High exposure to PAHs among coke-oven workers was linked to significant changes in the reproductive systems, with effects in sperm movement and morphology (Jeng et al., 2013). Heavy metals and fumes in $PM_{2.5}$ impacted the sleep quality of welders because metals such as copper, manganese and lead increased urinary serotonin levels, interrupting their sleep (Chuang et al., 2018).

4.2.5 Differential health impacts of air pollution in workers

Within industries, use of certain techniques or materials such as deep frying in cooking (Wei See et al., 2006) and reused frying oil (Ke et al., 2016) or equipment such as top-side ovens in steel plants compared to side-ovens in steel plants (Jeng et al., 2013) may be more pollutive. In a comparison of two different types of municipal waste incineration plants in Taipei, workers at fly ash treatment plants exhibited more cases of DNA breakages than bottom ash treatment plants, and within these plants, blue collar workers' cancer risk was higher than that of white collar workers (H.-L. Chen et al., 2010). Other hierarchies within the workplace also determine exposure. For instance, in a factory manufacturing decorative tiles, workers engaged in printing and mixing paints had a higher exposure than supervisors or those in the hand-painting section (Choy et al., 2004). Location of offices, such as within or outside the city center, may also impact indoor air quality of workplaces (Othman et al., 2018).

Axes of social stratification such as age, gender and class affect health impacts. Research on traffic conductors, factory workers and restaurant cooks study a purely male sample, whereas domestic cooking is mainly performed by and affects the health of middle-aged women, indicating the gendered nature of work. Workers with less education and lower income worked the longest hours, increasing exposure to pollution and its associated health impacts (Lyu et al., 2021). Laborers working for more years in incinerators reported greater health risks (H.-L. Chen et al., 2010). Stratified gender analysis in an office environment showed significant variations in the way men and women report exposure and health symptoms with women reporting higher levels of complaints related to mucosal and general symptoms from exposure to the dust level indoors. (Syazwan et al., 2013). Rural residents are more likely to cook using biomass such as wood or charcoal, rendering them at greater risk of chronic airway diseases than urban women (S. Liu et al., 2007).

However, in some cases, those that are typically considered less vulnerable also bear the health burden of pollution. Although indoor workers reported better health outcomes than outdoor workers like traffic conductors (Huang et al., 2012) or factory workers involved in welding (Lai et al., 2020), air-conditioning in indoor environments (Jones et al., 2006, 2008) was not found to significantly reduce pollution risks. While office workers are usually selected as a low-exposure (control) group, a study of foundries showed that PAHs had leached from the manufacturing to administrative unit (H.-H. Liu et al., 2010).

4.2.6 Solutions

The solutions identified by the evidence have largely called for efforts to reduce emissions. Air quality can be improved by boosting ventilation in indoor environments, by having good exhausting equipment or well-functioning air conditioners, and by reducing pollution and energy consumption (Hong et al., 2015; Lyu et al., 2021; Othman et al., 2018; Yu et al., 2015; Zamani et al., 2013). A transition to cleaner technology such as electric cooking stoves (S. Liu et al., 2007) or use of sustainable materials like eco-friendly paints (Lin et al., 2019) is essential. Sharing information to workers on air pollution exposure (Zamani et al., 2013) or on the use of appropriate protective personal equipment (Choy et al., 2004; Jeng et al., 2013) may mitigate risks. However, in highly polluting environments or high temperature environments like foundries, use of masks may be insufficient and infeasible (H.-H. Liu et al., 2010). Therefore, increased access to health protection and insurance coverage for prevention and treatment of illnesses in workers of polluting industries becomes crucial. Other measures like job rotation (Jeng et al., 2013) or reduction of work hours are also identified in the literature as ways to cut occupational exposure to air pollution (Puangprasert & Prueksasit, 2019).

4.3 Occupational exposure and sub-groups that are particularly vulnerable

This sub-section of the report presents key findings from an evidence-mapping exercise on occupational exposure to air pollution and identification of particularly vulnerable subgroups in East and Southeast Asia, accounting for age, gender, class, ethnicity, race and disability in East and Southeast Asia.

4.3.1 Methodology

Question Formulation

The question formulation process is similar to the one explained in section 4.1 for the review of occupational health, with a focus on exposure to the air pollutants. We developed a search string (Annex 4.2.1) and used it to identify matches in journal articles in the Scopus database (access provided by Chulalongkorn University Library).

Screening

The search yielded 1468 results, of which 1448 articles were written in English. These articles were then screened in Rayyan software to only include articles related to occupational exposure (including informal work, domestic work and specific factories), with study sites in East and Southeast Asia (based on country list) and publications that are either journal articles or reports.

The first round of screening selected articles based on the title and abstract. Only the articles that completely or partially mention occupational exposure to air pollutants were included. Ninety-nine papers were selected for the next step.

A second round of screening excluded papers that did not mention the location of study or study design in the abstracts and titles. Only the papers that focused on East and Southeast Asian countries exclusively or as a case study were included. This left 57 relevant papers.

We then downloaded full texts of the 57 articles. Out of these, five articles were not available for open access. Hence we downloaded 52 articles for full text screening. The full texts were reviewed completely and key information such as bibliographic information, location details, occupational exposure such as site and type of exposure, concentration and type of pollutant, parameters that influence exposure and differentiated impacts were analyzed and added in a codebook. The following sections describe the details of the remaining 52 articles.

4.3.2 Findings

a) Overview of descriptive statistics

Fifty articles reviewed were published in a journal, while two were conference papers. Eleven of the journal articles were published between 2000 and 2011 and 41 between the years 2011 and 2021, indicating an increased research interest in the topic in recent years.

The most common study methodology used by researchers to assess air pollutant exposure was experimental study design, which included questionnaire and pollutant measurement using monitors, human exposure and health analysis, followed by policy or occupational safety suggestions. Some studies include a comparison of the study data to that from local meteorology departments. Some studies compare the exposure between the indoor office workers (control population) and pollution-exposed workers (exposed population) in non-office environments such as manufacturing and food delivery. The questionnaires and analysis procedures followed were similar to those outlined in section 4.1.1.

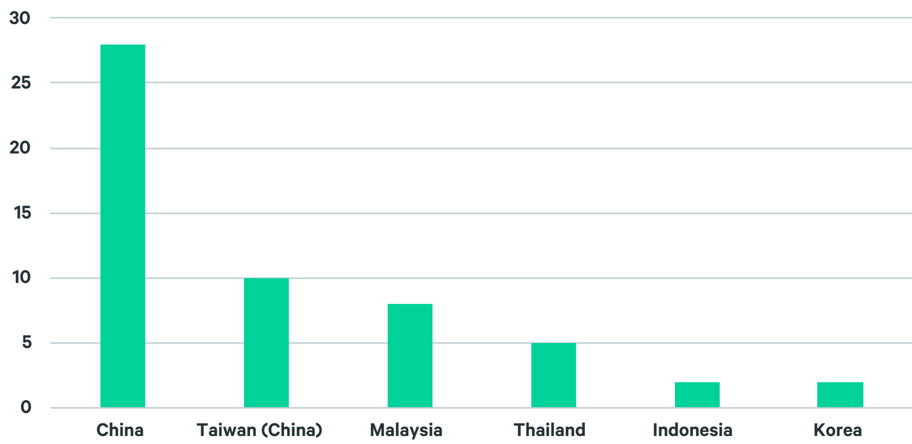


Figure 4.3: Article count by country

Even though the article search was carried out for all East and Southeast Asian countries, six countries were covered in our sample. The most articles found were for China, followed by Taiwan, Malaysia, Thailand, Indonesia and Republic of Korea, respectively (Figure 4.3). The lack of search results from other Southeast and East Asian countries could also be attributed to the narrow search string used for the evidence map.

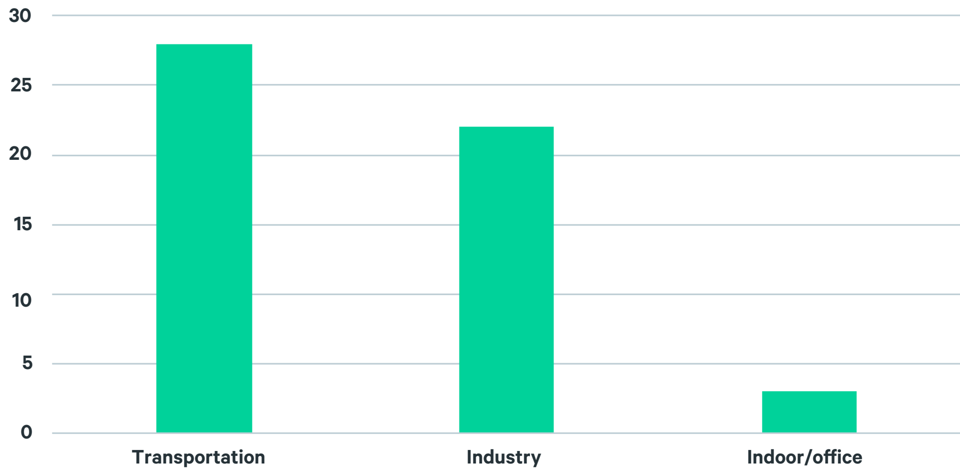
b) Occupational exposure according to sector and site exposure

Most papers (28 out of 52) focused on occupational exposure to traffic exhaust and ambient pollutants. The occupations included traffic police, food delivery, toll workers and mail carriers. Some studies examined exposure to specific manufacturing processes like coal-fired powers plants and welding. Of the 52 papers, 23 studies investigated exposure to indoor air pollution, including office buildings and printing shop emissions (See Table 4.2 for articles per sector.)

Table 4.2: Number of article occurrences per sector

Sector	Site/source of exposure	Number of article occurrences	References
Transportation-related			
Traffic police	Roadside traffic	9	(Huang et al., 2012; S. Liu et al., 2007; Putri Anis Syahira et al., 2019, 2020; Tan et al., 2017, 2018; Tang et al., 2021; Zhang, 2018; J. Zhao et al., 2013)
Cargo dock	Cargo and traffic exhaust	1	(B. Liu et al., 2021)
Food delivery services	Road traffic	1	(Yang et al., 2020)
Public transport	Road traffic	5	(Haryanto & Pratiwi, 2020; Jinsart et al., 2012; Jones et al., 2006; Kongtip et al., 2012; Pratiwi & Budi, 2020)
Tollways	Toll gate	5	(Khamraev et al., 2021; B. Liu et al., 2021; C.-F. Wu et al., 2010; Zhang, 2018; Y.-J. Zhao et al., 2018)
Taxis (motorcycle and car)	Road traffic	3	(Arphorn et al., 2018; Miller-Schulze et al., 2013; C.-F. Wu et al., 2010)
Mail carriers	Road traffic	2	(Chan & Wu, 2005; C.-F. Wu et al., 2010)
Roadside vendors	Road traffic	1	(Jones et al., 2008)
Municipal household waste workers	Road traffic	1	(Lee et al., 2015)
Car park operators	Car exhaust	1	(Yan et al., 2017)
Industry-related			
Coal-fired power generation	Coal-fired power generation Process.	1	(Khamraev et al., 2021)
Print shops	Printing emissions	1	(B. Liu et al., 2021)
Welding	Welding fumes	1	(Lai et al., 2020)
Electronic waste recycling	E-waste dismantling process	2	(Puangprasert & Prueksasit, 2019; Sheng et al., 2011)
Selective laser sintering workers	Selective laser sintering process	2	(Damanhuri, Hariri, et al., 2019; Damanhuri, Subki, et al., 2019)
Spray painting	Spray painting workers	1	(Lin et al., 2019)
Heavy-duty diesel engine testers	Engine testing workshops	1	(B. Wang et al., 2018)
Cooking	Restaurants/outdoor BBQ	3	(Ke et al., 2016; J. Wang et al., 2011; C.-C. Wu et al., 2015)
Oil drilling workers	Offshore drilling areas	1	(H. Xu et al., 2016)
Steel-making and direct reduction plant	Furnace, ladle furnace, ladle handling, continuous casting machine, crane operation,	1	(Nurul et al., 2016)
Fluorochemical manufacturing plant	Manufacturing	1	(Gao et al., 2015)
PVC	Manufacturing	1	(W. Wang et al., 2015)
Foundry	Core making, melting furnace, molding, sand shakeout, grinding, sand recovery	1	(H.-H. Liu et al., 2010)
Bottom ash recovery and fly ash treatment plant	Bottom ash recovery and fly ash treatment processes	1	(H.-L. Chen et al., 2010)
Temple workers	Incense smoke	1	(Kuo et al., 2008)
Furnishing and electronic equipment	Organophosphorus flame retardant manufacturing	1	(M. Chen et al., 2019)
Textile industry	Manufacturing processes	1	(L. Xu et al., 2015)
Automobile	Manufacturing processes	1	(L. Xu et al., 2015)
Indoor			
Office	Printing emissions	3	(Huang et al., 2012; Murnira et al., 2020; Nezis et al., 2019)

Figure 4.4: Number of articles based on sector



The clear dominance of the papers focusing on transportation-related occupational exposure raises the possibility of bias that air pollution is largely a vehicular exhaust problem (Figure 4.4). Also, the large number of studies done on air pollutant exposure by traffic police, followed by public transportation drivers, points to the difficulty implementing the right research methods to other occupations exposed to vehicular traffic (like municipal waste workers and taxi workers), due to prevalence of informal workers in the sector and variable traffic routes and exposure times in Southeast Asia. Furthermore, the relatively limited number of articles focusing on occupational exposure to manufacturing emissions highlights the need to address this sector of air pollution.

c) Parameters that influence exposure

1. Location:

The concentration and the level of the worker's exposure to a certain pollutant largely depends on the source of the pollutant and distance between the pollutant source and worker. This is illustrated by Khamarev et al. (2021), who studied occupational exposure to coal dust in a coal-powered power plant. The study concluded that the workers in the coal handling system (the process with maximum coal dust production), had the highest coal dust exposure, compared to those in the boiler system area. The workers in the boiler system (the process farthest from the coal handling system), had the lowest exposure. A study by H-L. Chen et al. (2019) found that the exposure for certain pollutants varies in different stages of processing coal. In recycling of electronic waste, certain types of organophosphorus flame retardants like Triphenyl phospate (TPHP/TPP), Tris(2-chloroethyl) phosphate (TCEP) and Tris(1,3-dichloroisopropyl) phosphate (TDCIPP), were observed to be highest during electronics disassembly, compared to the other stages of recycling (Khamraev et al., 2021).

Furthermore, different locations contain different types of pollutants in variable quantities. The results by Othman et al. (2020) suggest that office activities, such as printing and photocopying, affect indoor O_3 concentrations, while $PM_{2.5}$ concentrations are affected by indoor-related systems such as airconditioning systems. A study by Tan et al. (2017), compared the locational influence of traffic exhaust pollution and found that "the average $PM_{2.5}$ concentration in the intersections of main roads was 2.61 times higher than in offices and about 13 times as high as the level specified in the air quality guidelines published by the World Health Organization".

2. Duration of exposure:
A pollutant's health impacts increases exponentially with the length of time a person is exposed to it. For example, a paper by Tang et al. (2021) studies the traffic exhaust health impacts on traffic police officers and suggests that long-term exposure to ambient air pollution is associated with higher incidences of hyperuricemia (elevated uric acid in the blood that causes effects like joint stiffness and severe joint pain).

Additionally, a study by Yang et al. (2020), which studied occupational exposure to emissions from traffic, stated that long-term exposure to traffic pollutants can cause chronic respiratory and cardiovascular diseases, with higher mortality rates, as opposed to people exposed to pollutants for a shorter time. Furthermore, according to a study by Lyu et al. (2021), the number of years of exposure is directly proportional to the compounded effect of the exposure. This study found that the concentration of PM_1 exposure reading for the print shop workers who worked for more than 10 years was 9427.79 particles per cubic centimeter (cm^3), while that of the ones who worked for less than 10 years was 8340.99 particles/cm^3. Thus, proving that longer term exposure to a pollutant can lead to higher levels of the pollutant detected.

3. Compounded pollutant source effect
Pollutants from multiple sources in the same area can drastically raise the level of exposure. A study carried out by B. Liu et al. (2021) on occupational exposure of cargo freight workers indicates study areas near industrial parks showed higher occupational exposure due to higher concentration of pollutants from industrial emissions, higher concentration in the surrounding areas and cargo ship emissions.

4. Seasonal variations
Air pollutants in surrounding areas show variations in concentrations depending on season, temperature and humidity in the atmosphere. A study by Yan et al. (2017) regarding occupational exposure of underground car park operators says that air pollutants in the car parks show obvious seasonal variation, being higher in winter than in summer due to lower temperatures and lower humidity in winters.

5. Physical barriers:
Introducing a physical barrier in between the pollutant source and the workers can largely reduce the amount of exposure and human impact. In a study about occupational exposure of public transportation drivers found that blood lead levels for non-air-conditioned buses was higher than that of the air-conditioned buses, indicating that having a physical barrier in air-conditioned buses, in the form of closed doors and windows, reduced the exposure (Jones et al., 2006). Another study of bus drivers confirms the same findings that $PM_{2.5}$ exposure concentrations in non-air-conditioned bus drivers (323.81 ± 169.19 µg/m³) for their study location was significantly higher than those in air-conditioned bus drivers (206.46 ± 94.31 µg/m³). However, this was opposite for CO_2 concentrations. Higher CO_2 concentration levels were observed in air-conditioned buses than non-air conditioned buses (Kongtip et al., 2012).

4.3.3. Differentiated impacts

Occupational exposure: A study that looked at the effect of vehicular emissions on ambient PAHs highlighted that the PAH exposure for highway toll workers is 15 times higher than that of students on a university campus. Also, the exposure of policemen working at a road intersection were found to be 40 times greater than on the university campus. Toll way workers' PAH exposure was significantly higher than vehicle inspection workers (Zhang, 2018). In the case of particulate matter, actively exposed professions like motorcycle taxi drivers work in close proximity to vehicular exhaust gas from tail pipes that emit PM_{10}. Inhalation of PM_{10}-heavy exhaust gas has been linked to a 3–8% increase in relative risk of death from cardiorespiratory diseases (Arphorn et al., 2018). Traffic police have been shown to be "exposed to at least 2 times higher $PM_{2.5}$ in their work area as compared with the control group" (Tan et al., 2017, p. 333). Another study that looked into occupational exposure of the municipal waste collectors who fill the trucks found that the exposure of waste collectors to organic carbon, elemental carbon and total carbon was much higher than that of the waste collection truck drivers (Lee et al., 2015). This is also confirmed by another study that found that the concentration of PM_{10} at the roadside (210 ± 70 μg/m^3) was significantly higher than inside shops (130 ± 40 μg/m^3) (Jones et al., 2008). A study that compared all public transport drivers found that tuk-tuk drivers were the ones most exposed to $PM_{2.5}$ and PM_{10}, followed by non-air-conditioned bus drivers (Jinsart et al., 2012).

Duration of exposure: Continuous exposure over long periods of time can lead to an accumulated health effect. A study by Lyu et al. (2021) found that most significant changes of cardiopulmonary function were found in exposed print shop workers with more than 10 years of working experience.

Urban vs rural: Congested road traffic and higher industrial activity in and around urban areas give rise to high concentrations of air pollutants, leading to higher exposure among urban residents. A study by Tang et al. (2021) pointed to the higher prevalence of hyperuricemia in urban residents compared to rural residents (14.9% to 6.6%). Furthermore, the distance a particular pollutant travels depends on the type of pollutant, which leads to different levels of concentrations of pollutants at different distances from the souce. Yang et al. found that NO_2, CO and $PM_{2.5}$ were mainly concentrated near the polluted urban areas, but SO_2, O_3, and PM_{10} were detected away from the city where they originated (2020).

Location: Khamraev et al. (2021) found the highest concentrations of heavy metals like chromium and nickel in industrial areas. This leads to greater exposure to these pollutants among people living closer to the industrial area as opposed to people living a little farther away. Proximity to industrial pollutants leading to higher amounts of exposure by workers and the people living in the vicinity has been widely studied. High amounts of heavy metal elements in $PM_{2.5}$ were observed in air around factories and workshops handling heavy metals (Khamraev et al., 2021). A study about electronic waste recycling by Puangprasert and Prueksasit (2019) found workers who dismantle the waste indoors to be exposed to higher concentrations of cadmium, copper and lead than workers working outdoors. The study also found that workers are at a higher risk for flame retardant exposure than non-working populations, and the exposure is higher in cities than in the countryside (M. Chen et al., 2019).

Children: Air pollutants affect various population groups differently. The most obvious vulnerable group is children living in the relatively highly polluted urban areas or near industrial and commercial areas, due to their lower weight and higher frequent hand-mouth activities (M. Chen et al., 2019). A study by M. Chen et al. (2019), found that the estimated daily intake of flame retardants among "toddlers (137 nanogram per kg per day (ng/kg/d)) was approximately 10 times of that for adults (13.7 ng/kg/d)". This differentiated vulnerability was also confirmed by a study by Khamraev et al. (2021) that studied exposure to air pollutants in China and Malaysia (2021). The study found that lead concentration was highest among children residing in industrial areas, followed by commercial, residential, educational and park areas. The most common exposure pathways were through the skin and through inhalation. None of the shortlisted literature focused on or described air pollution's effects on youth workers or child labor.

Gender: Though most of the studies did study occupational exposure to both men and women, only two studies explicitly mentioned the different genders' vulnerability (Tang et al., 2021). Huang et al. (2012) studied $PM_{2.5}$ (particulate matter of sizes 2.5 or less) exposure between different occupations, highlighting that women police officers were distinctly few compared to male police officers in Taiwan, leading to difficulty in confidently declaring differences in gendered vulnerability. This was also highlighted in the study by Tang et al. (2021), where even though the study found lower prevalence of hyperuricemia among women compared to men, suggestive evidence of effect modification attributed by gender was observed leading to differentiated vulnerability between men and women. Among the papers we studied, we found a lack of sufficient literature highlighting gendered impacts. This highlights the importance and need for more studies on gendered impacts of air pollution. It also indicates that gender studies involve a lot of variables and in general are rather complex to study, leading to them to be neglected in the body of literature.

4.4 Conclusion

Through our evidence review of the social, health and occupational impacts of air pollution among workers, we synthesized existing knowledge and identified gaps on the subject. Since there were few articles on the social impact of air pollution on labourers in East and Southeast Asia, we extended the focus of the review to a global span. However, these impacts may well be translated to the Asian region. We find that certain groups of workers may be underrepresented in scientific studies, such as informal workers, child workers, or workers in certain locations such as rural, small town or peri-urban sites. Social axes of stratification such as gender, race, age and class (which interact with job hierarchy and job roles) all affect workers' exposure to air pollution and leaves the poor disproportionately vulnerable to its health effects. Use of outdated equipment, materials or mechanisms at work may also lead to undue occupational risks.

Though we study the social and health impacts as distinct domains, they are interconnected. Severe health impacts can lead to other labour market and social impacts such as low workforce participation, lower productivity or more informalization, thereby compounding vulnerability of some groups of workers like outdoor vendors and policemen. However, the literature reviewed in the differentiated health impacts section, for instance, largely highlighted public health and therefore these social interactions were not touched upon. Many studies did not explicitly mention the formality or informality of the enterprises studied, so we do not know enough about the effect of labour and employment policies on social, labour market and health outcomes. For instance, labour policies such as social security coverage for informal workers may lead to greater awareness of occupational air pollution exposure and better health outcomes. What is clear is that more inter- and trans-disciplinary research in the region can unpack these spillover effects and policy impacts.

The next chapter summarizes the existing state of policy-making in the air pollution, labour and occupational exposure domains.

Chapter 5: Policies regulating air pollution, labour and exposure in the workplace

By Diane Archer, Ha Nguyen and Dayoon Kim

5.1 Air pollution policies

5.1.1 Methodology

In this section, we ask what air pollution control policies are in place in the region. In 2015, the United Nations Environment Programme (UNEP) conducted a review of national policies that address air quality, including countries in Asia, which were published in the 2016 Actions on Air Quality report (UNEP, 2016) and updated in 2022. This report includes several action area categories we used as a basis for our review. As the detailed 2022 dataset was not available at the time of writing, the research team used the 2016 report as a baseline and sought to find more recent data through web searches on categories including air pollution standards, vehicle emissions standards, sulphur content standards and use of solid fuels, and also added a category of whether or not the country has an air quality act or similar legal framework addressing air quality.

5.1.2 Main findings

Table 5.1 outlines the main results of this review. Most countries in the region have a legal framework specific to air pollution – though in the cases of Myanmar, Thailand and Brunei, this falls under broader environmental quality legislation. Lao PDR does not appear to have a legal framework addressing air quality.

With regards to national ambient air quality standards, three countries do not have any standards in place: Myanmar, Cambodia and Brunei. No country has set the annual mean $PM_{2.5}$ standard to the WHO guideline level of 5 μg/m^3 – Singapore is the closest at 12μg/m^3, while the remaining countries are variously at WHO interim target 1-3 (in China the target varies between urban and rural areas). Annual mean $PM_{2.5}$ interim targets 4 to 1 are 35, 25, 15, 10 μg/m^3, respectively.

Most countries are implementing EURO vehicle emissions standards, with the exception of Cambodia, Myanmar and Lao PDR. Singapore is the most advanced with EURO VI in effect, while most countries are implementing EURO IV. For fuel sulphur content, Myanmar, Lao, Cambodia, Indonesia and Myanmar have not yet implemented the 50ppm maximum limit.

Table 5.1: Summary of air quality measures in the region (authors' own)

	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam	China	Taiwan	South Korea	Mongolia
Access to non-solid fuels – do > 85% of the population have access to non-solid fuels?	NA	88% use solid fuel	47% use solid fuel, 79% in rural areas	98% of rural population use solid fuel	NA	93% use solid fuels	49% use solid fuels	NA	24% use solid fuels	51% use solid fuels, 72% in rural areas	31% use solid fuels, 71% in rural areas	NA	NA	70% use solid fuels
Vehicle emissions standards – EURO 4 or above?	target Euro IV by 2016, not clear if achieved.	pre-Euro	EURO IV (petrol from 2018, diesel from 2021)	none	Euro IV for petrol	none	Euro IV	Euro VI	Euro IV	Euro IV	Euro IV	Euro V (from 2021)	Euro IV	Euro II
Fuel sulphur content – is maximum allowable sulphur content 50ppm?	50ppm (diesel)	1,500 ppm	3,500 ppm	2,500ppm	50ppm (diesel)	2,000ppm	50ppm (diesel)	10ppm	50 ppm (diesel and petrol)	50ppm (diesel)	10ppm	10ppm	50ppm	5,000ppm
Laws and regulations – is there a Clean Air Act?	Environmental Protection and Management Order 2012 includes air pollution control	Circular on Measure to Prevent and Reduce Ambient Air Pollution (2020)	Government Regulation (PP) No. 41/1999 on Air Pollution Control;	No legal framework	Environmental Quality (Clean Air) regulations 2014	Environment Conservation Law 2012but no regulations or standards	Philippine Clean Air Act 1999	Environmental Pollution Control Act 1999	Various policies and acts mention pollution but no overarching law	Articles 111 and 112 of the Environmental Protection Law 2020	Air Pollution Prevention and Control Law (New Air Law) 2016	Air Pollution Control Act (2018 amendment)	Clean air Conservation Act (rev 2019)	2010 Law on Air Quality (amended 2015)
Are there Ambient Air Quality Standards (AAQS)?	NA	NA	WHO interim target 3	No AAQS	WHO interim target 1	No AAQS	WHO Interim target 2	12 ppm	WHO interim target 2	WHO interim target 2	WHO interim target 1	WHO interim target 3	WHO interim target 3	WHO interim target 2

Use of solid fuels, a particular issue with indoor air pollution, substantially varies between urban and rural areas in most countries. Cambodia, Lao PDR, Myanmar and Mongolia see the highest rates of solid fuel use, though the rate remains high in Indonesia's rural areas, as well. Data could not be found for Singapore, Taiwan, Republic of Korea, Malaysia or Brunei, which suggests levels of solid fuel use are minimal.

This quick review suggests that the low-income countries in the region (Cambodia, Lao PDR and Myanmar) remain the least advanced in their implementation of clean air measures and still lack comprehensive policy frameworks to facilitate this.

5.2 Review of labour and social security policies in relation to air pollution

5.2.1. Method

This review addresses two main questions: 1) How do national policies on labour and social security address occupational air pollution? and 2) Who benefits and who is left out? We reviewed national policies on labour and social security available on the ILO's database of national labour, social security and related human rights legislation (NATLEX). The process consisted of three steps: identifying the policies, reviewing of policies with keyword search and coding the results (see details in Annex 7). The results were compiled into an Excel sheet that indicate area of regulation, duty bearers, target groups, gender and social equity considerations, as well as references to air pollution. Based on how the policies address air pollution, we categorized air pollution into three types: 1) chemical substance, 2) gas and fume, and 3) particulate matters which are referred to as dusts in some policy documents.

To assist the analysis, we further ask:

- Do they acknowledge air pollution as a hazardous working condition?
- Which type of air pollution is regarded as an occupational health risk?
- Which countries mandate compensation for workers affected by air pollution?
- What are the required measures?
- Who is protected or targeted by the policy?

5.2.2. Main findings

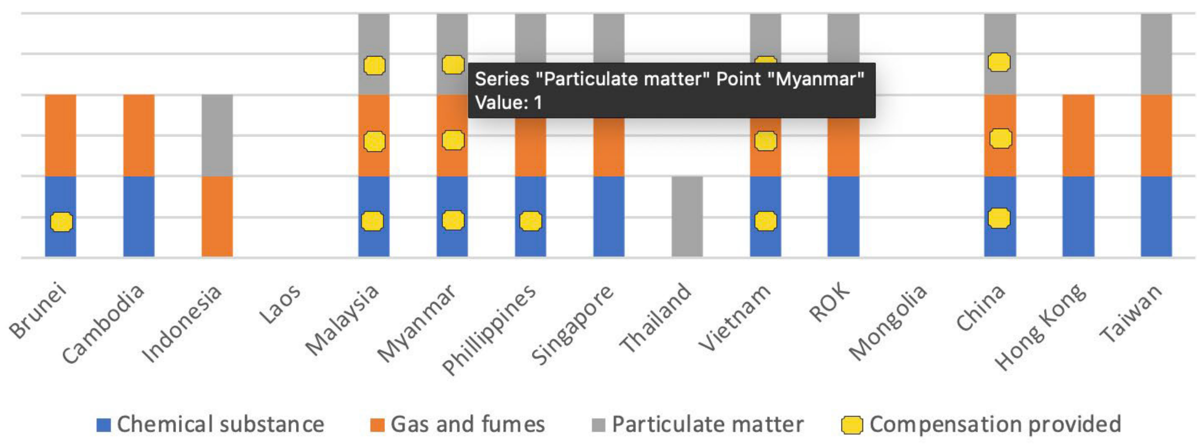
Air pollution in national labour and social security policies:

Most countries view air pollution as a work hazard: The review of policies related to air pollution control (see the list of the policies in table 5.2) shows that most countries reviewed acknowledge air pollution as creating hazardous working conditions and address occupational health and safety policies, except Lao PDR and Mongolia. These policies primarily regulate industrial air pollution through measures and standards for factories and industrial facilities, such as inspection of chemical substances, hazardous gases and dust, proper ventilation, the use of protective equipment and, sometimes, working age.

Not all kinds of air pollution equally regarded as occupational health risks: Figure 5.1 shows that among the three types of air pollution, gas and fumes pollution is recognized as an occupational risk by 12 countries, followed by chemical substance (11 countries) and particulate matter (10 countries). Notably, Brunei, Cambodia and Hong Kong do not consider particulate matter exposure as an occupational risk. Meanwhile, Thailand policy only addresses risk from particulate matter exposure.

Compensation for occupational diseases caused by air pollution is not always guaranteed: Despite acknowledging health risks of air pollution exposure in occupational safety and health

Figure 5.1: Pollutants regarded as cause of occupational diseases



policies, most countries focus on protective and regulatory measures as well as penalties for factories industries when they breach regulations without addressing compensation. The yellow marker in Figure 5.1 indicates the causes of occupational disease that allow for worker compensation. The figure shows that only six countries require compensation to affected workers. Among them, Brunei and Philippines limit the compensation to diseases caused by chemical substances only.

Who benefits and who is left out?

Labour protection policies target industrial and waged workers, while overlooking informal workers exposed to various pollution sources. Out of 29 policies related to occupational safety and health, eight polices[3] apply to the industry and factory sector, four policies to construction[4], one to agriculture[5] and one to the mining sector[6]. Except Singapore and Thailand, which only regulate occupational safety in industrial sector, the remaining countries apply protective measures to waged workers in general. This excludes many groups of self-employed, informal, low-skilled and domestic workers who are exposed to various pollution sources, including from industrial activities. Meanwhile, Myanmar and the Philippines included broader groups of workers and employers to be protected under the Occupational Safety and Health law. Myanmar's Occupational Safety and Health Law (2019) defines a worker as "a person who makes a living by using his/her physical or intellectual skills in the Workplace to which this Law applies" (p1). However, the word "workplace" defined by the law indicates industries and businesses that do not encompass some informal sectors that employ workers such as domestic workers, street vendors, motorbike riders, seasonal agricultural workers and wastepickers (see pp 3-4). Philippines' Occupational Safety and Health Standards (1989) indicates that employee shall mean "any person hired, permitted or suffered to work by an employer," and an employer is defined as "any person acting directly or indirectly in the interest of an employer, in relation to an employee" (p1). Overall, there is a lack of legal mechanisms to protect informal workers against sources or impacts of air pollution, particularly when they do not or are unable to register for social security schemes.

Access to social security through employment compels informal workers to shoulder the burden of medical care. The majority of countries[7] grant social security access to certain groups of employees through employers by contributing to national social security fund. Some countries

3 Those are from Brunei, Malaysia, Myanmar, Philippines, Singapore and Hong Kong
4 Those are from Brunei, Philippines, Singapore and Thailand
5 From the Philippines
6 From China
7 These countries include Cambodia, Indonesia, Lao PDR, Malaysia, Philippines, Singapore, Thailand, Vietnam, South Korea, Mongolia, and Taiwan

grant access to specific groups of informal workers. For example, Cambodia[7] includes "seasonal or occasional workers" as part of the employee groups to be protected. Some countries[8] allow citizens or self-employed workers to contribute independently to social security funds. This policy excludes cross-border informal migrant workers who often receive lower pay than local workers. No concrete data on the percentage of informal workers registered to social security system is available; however, it is safe to assume that not all of them have access to social security. Given the increasing number of informal workers exposed to worsening air pollution in urban areas, it is likely that the cost of healthcare will increase. Such costs are shouldered by low-income informal workers, who are often invisible in the national economy.

Table 5.2: Policy related to air pollution control and protection in the East and Southeast Asia countries

Country	Policy related to air pollution control and protection
Brunei	Workmen’s Compensation Act, 1957 (Cap. 74) (No. 5 of 1957).
	Workplace Safety and Health (Construction), Regulations (No. S. 35) (2014)
	Workplace Safety and Health Order (No. S 44) (2009)
Cambodia	Prakas No. 106 of 2004 on the Prohibition of Hazardous Child Labour (MoSALVY) (2004)
Indonesia	Law No. 1 of 1970 on Occupational Safety. (1970)
	Minister of Manpower and Transmigration Decree No. Kep.235/MEN/2003 concerning Jobs that Jeopardize the Health, Safety and Morals of Children (2003)
Lao PDR	NA
Malaysia	Occupational Safety and Health Act (No. 514) (1994)
	Factories and Machinery Act (Act 139) (1967)
	Workmen's Compensation Act (Act 273) (1952)
Myanmar	Factories Act (No. LXV) (1951)
	Occupational Safety and Health Law (Pyidaungsu Hluttaw Law No 8 of 2019) (2019)
	Shops and Establishments Law (Pyidaungsu Hluttaw Law No. 18/2016).(2016)
Phillippines	Guidelines Governing Occupational Safety and Health in the Construction Industry (D.O. No. 13 of 1998). (1989)
	Guidelines Governing Occupational Safety and Health in the Construction Industry (D.O. No. 13 of 1998) (1998)
	Guidelines on Maritime Occupational Safety and Health (D.O. No. 132-13). (2013)
	Department Order No. 149 of 2016 on the Guidelines on Assessing and Determining Hazardous Work in the Employment of Persons Below the Age of 18 Years. (2016)
	Department Order No. 154-2016 Safety and Health Standards on the Use and Management of Asbestos in the Workplace.(2016)
Singapore	Workplace Safety and Health (General Provisions) Regulations 2006 (No. S 134)., 2006) Workplace Safety and Health (General Provisions) Regulations (No. S 134) (2006)
	Workplace Safety and Health (Construction) Regulations. (2007)
	Workplace Safety and Health (Asbestos) Regulations (No. S. 337) (2014)
Thailand	Ministerial Regulation Prescribing the Standard for Administration and Management of Occupational Safety, Health and Environment for Construction Work, B.E. 2551 (A.D. 2008) (2008)
Viet Nam	Circular No. 10-1998-TT-BLDTBXH providing guidelines for implementation of regulations on personal protective equipment (1998)
	Law on Occupational Safety and Health (Law No. 84/2015/QH13) (2015)
Republic of Korea	Occupational Safety and Health Act (No. 4420) (1990)
Mongolia	NA
China	Regulations on Labour Protection in Workplaces Where Toxic Substances Are Used (Adopted at the 57th Executive Meeting of the State Council on April 30, 2002, promulgated by Decree No.352 of the State Council of the People's Republic of China) (2002)
	Law of the People's Republic of China on Safety in Mines. (1992)
Hong Kong	Occupational Safety and Health Ordinance (No. 39 of 1997) (Cap. 509) (1997)
	Factories and Industrial Undertaking (Asbestos) Regulation (L.N. 74 of 1997) (1997)
Taiwan	Occupational Safety and Health Act (1974)

Source: NATLEX , ILO database

5.3 Policies on urban public space

5.3.1. Methods

We explored the intersection between public space, air quality and the world of work by asking: How do public policies address air quality and regulate spaces for informal workers, such as street vendors whose livelihoods depend on access to public spaces? To understand the normative framing of air pollution and informal sector in urban public space, we examine the Public Space Policy Framework developed by (UCLG, 2016a). United Cities and Local Governments in 2016. UCLG is a global network of city, local and region governments that aims to increase influence of local governments in global political arene. The purpose of this Public Space Policy Framework is to assist local governments in planning and managing public spaces.

To understand how cities in the region address air pollution and informal sector in policy and practice, we also reviewed smart city projects launched by ASEAN in 2018 (ASEAN, 2018a). Smart city is the concept that technology and digital solutions can address urban problems such as air and water pollution, traffic congestion, rising inequality and promote urban smart and sustainable development.

5.3.2. Findings

Public space-related policies regard air pollution and informal sector as a matter of access to physical spaces and facilities. Air pollution, according to the Public Space Policy Framework, could be addressed by “incorporating trees and natural elements” in public places and increasing access to green spaces (UCLG, 2016b, p. 22). This framework regards the informal sector as a matter of designating space for economic opportunities and fostering urban-rural connection, particularly for food supply. Such an access approach is mirrored in the development of ASEAN cities in both physical and virtual aspects. The review of the smart city projects shows that the sectors receiving most investment are public transport infrastructure, data hubs and digitalization of public services and commerce. In contrast, access to public services such as health care, education and low-cost housing, which would benefit low-income groups, are less prioritized (Table 5.3).

While improving public transit service and traffic management can result in reduced air pollution caused by transportation, the rationale for those investments is often to improve accessibility and efficiency in mobility, rather than reducing air pollution. For example, even though road transportation is the main air pollution source in Bangkok (Pollution Control Department, 2019), the purpose of constructing the Transportation Hub at Bang Sue area is to “overcome the existing infrastructural pressure” and “to reducing commuting time” (ASEAN, 2018b, p. 46).

Workers in the informal sector are regarded as public space occupants. According to the ASEAN’s Smart City Action Plan (ASEAN, 2018b, p. 9), the presence of those who use public space for their livelihoods is considered undesirable, causing traffic congestion, therefore, they should be re-located from street areas.

The access approach in public space policies does not effectively address causes of air pollution, neither does it recognize exposure and impacts of air pollution on informal sector work. By framing public space simply as a physical location and its function, public space policies are unable to address air quality and its causes, and are also oblivious to human physical and emotional experiences associated with those spaces. Public space policies deal with physical occupation of space by human activities, infrastructure and physical facilities. As a result, the only informal worker group mentioned in public policies is street vendors. Other informal worker groups such as motobike taxi drivers or construction workers are not included because they do not take up space, but are part of traffic or construction sites. Nevertheless, as the UCLG’s public space policy framework strongly promotes the principles of social inclusion, democratic process and equals right to a city in the governance of urban space, there are windows for disadvantaged groups to reframe and position the issues of informal sector and air pollution in public space policies.

Table 5.3: Investment priorities of smart city projects in ASEAN

	SECTOR	Tranportation			Digitalisation						Public spaces			Public services				Resources management						
	CITY	Public transport service	Urban/Transport planning	Traffic management	Database	Surveilance	Digitalised public services (edu, health, admin)	Online tax service	E-commerce and cashless technology	Online platform for business ideas	Street and public space management	Construction of pedestrian footpath	Construciton of bycicle lane	Affordable housing	University	Health care	Emergency response	Renewable energy integration	Waste management	Water magement	Integrated flood management	Wetland restoration	Cultural conservation	Tourism
1	Bandar Seri Begawan																		x					x
2	Battambang										x								x					
3	Phnom Penh	x									x													
4	Siem Reap										x													x
5	Makassar							x								x								
6	Banyuwangi								x															x
7	DKI Jakarta								x	x														
8	Luang Prabang											x										x		
9	Vientian		x																x					
10	Johor Bahru				x															x				
11	Kuala Lumpur				x							x	x											
12	Kota Kinabalu	x																	x					
13	Kuching			x																	x			
14	Nay Pyi Taw													x	x									
15	Mandalay			x															x					
16	Yangon	x												x									x	
17	Cebu	x		x																				
18	Davao	x		x																				
19	Manila						x																	
20	Singapore						x		x															
21	Bangkok	x	x																					
22	Chonburi																	x	x					
23	Phukhet				x	x																		
24	Da Nang			x																x				
25	Hanoi			x																				
26	Ho Chi Minh				x												x							
		6	2	6	4	1	2	2	3	1	3	2	1	2	1	1	1	1	6	1	1	1	1	3

Sources: Concept Note for ASEAN Smart City Network, n.d.

5.4. Initiatives addressing air pollution in the world of work

5.4.1 Methods

In this section, we carry out a desk-based review of non-governmental initiatives[8] that address air pollution in the world of work. This review addressed three questions: 1) What are the initiatives addressing air pollution in the world of work in the reviewed countries? 2) How have gender and social equality been addressed in those initiatives? And 3) Who are active actors in this area?

Data for the review come from two sets of sources: 1) bibliographic databases and 2) organizational websites, articles, blog posts, and project documents available online. Each source required a different method for the search. Regarding the former, we adapted systematic review approach. Regarding the latter, we conducted a manual Google search using key words (see detailed search string and screening results in Annex 6).

5.4.2. Main findings

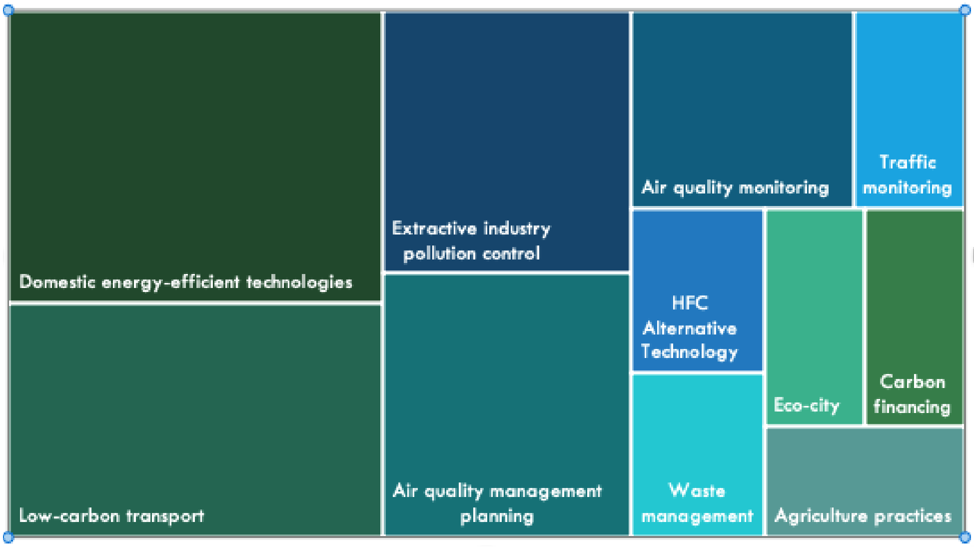
Initiatives and actors addressing air pollution in the world of work: In this review, the world of work indicates labour and employment, including both paid and self-employment, short-term, part-time and seasonal employment (Hussmanns et al., 1992). For example, employers, own-account workers, unpaid family workers and persons performing domestic work for own or household consumption, and members of producers' cooperatives should be regarded as self-employed (ILO, 1993). Also, public space is a livelihood asset for many urban informal workers (M. Chen et al., 2018). Despite their important roles in the economy, they are largely invisible in the urban space policies and social protection measures (M. Chen & Beard, 2018). Therefore, the

8 This section focused on the NGO initiatives and actions rather than ones led by the governments, as the government initiatives are often operated by its policies (covered in Section 5.1-5.3) and thus included as part of the policy engagements. Although governments are not the lead implementers of the projects examined in this section, they were often partners and key stakeholders to these initiatives, which highlight the relevance of their role in these actions.

team included initiatives that might have indirect impacts on informal workers in open and public spaces, such as those addressing industrial emissions and pollutions.

We have identified 23 projects that aim to address air pollution in Southeast and East Asia countries (see the list of project in Annex 8). None of them intend to target labour and employment, but we selected them because they might have implications directly or indirectly on the world of work. This limited selection of projects is by no means close to the actual number, but they might reflect the common approaches and discourses in air pollution control. Figure 5.1 shows thematic interventions of these projects; the size of the boxes corresponds to the number of projects identified on the same theme, not their geographical nor financial scope. We summarize them below in the order of prevalence.

Figure 5.1: Thematic interventions on air pollution control



Domestic energy efficient technologies (such as cook-stove and insulation material): We found five projects that aim to reduce indoor domestic air pollution caused by burning of biomass and coal for cooking and heating. Interventions mainly focused on market-based approaches, social marketing and deployment of improved cookstoves, and insulation materials. For example, the Switch Off Air Pollution (2018–2021) Initiative of Mongolia, led by Geres Acting for Climate Solidarity, has indicated how the absence of heating infrastructure forced people in districts of Ulaanbaatar, Mongolia, to heavily rely on cheap and low-quality coal for household and cooking needs, which in turn contributes to widespread health and respiratory problems (SWITCH-Asia, 2020). The project also acknowledges that the current situation puts further pressure on low-income families who spend a larger proportion (up to 40%) of their income on heating fuels (ibid.). In a similar light, the project Clean Air Green Cities of Viet Nam, implemented by the Green Generation Network and Center for Living and Learning for Environment and Community (Live & Learn), addresses domestic work and air pollution exposure. The project assesses that the current practice of utilizing coal for food preparation and traditional cookstove system has caused severe air pollution and health impacts that disproportionately affect women, and especially the poor. Two other projects concerning domestic labour, which were conducted in Lao PDR, focus on the distribution and increased awareness of the effectiveness and health benefits of improved cookstoves.

Low-carbon transportation: We found five projects that aim to reduce carbon emission caused by transportation. Their interventions include introducing low-emission transport policy, urban mobility planning, development and deployment of low-carbon transport technology and public transport. Except the project on adoption of efficient and clean technologies in global

BOX 1. MITIGATING MERCURY EMISSIONS AND AIR POLLUTION IN GOLD MINING

The use of mercury in gold mining poses health hazard to workers in gold mines as well as residents nearby mining sites, through inhaling mercury vapour, contacting mercury, and consuming contaminated food. To curb anthropogenic mercury release, in 2002, UN agencies(*) launched the project "Awareness Campaign and Technology Demonstration for Artisanal Gold Miners." The project was conducted in 6 countries, i.e., Brazil, Indonesia, Lao PDR, Sudan, Tanzania, and Zimbabwe. It involved nearly 2 million artisan miners and supported more than 10 million dependents in total.

The project comprises 3 main components: 1) research on pathways of mercury contamination and their impacts on health, as well as social environmental and economic conditions of miners and local communities; 2) training and raising awareness of workers, communities, the public and relevant government agencies on cleaner extraction technologies (e.g., mercury confinement/pool, mercury recycling, bio-sand filters, sluice boxes and retorts); 3) advocating for regulatory framework on mercury trade and use. Particularly in Indonesia, the project supported the development a legal framework to formalize the rights of indigenous miners in collaboration with the Ministry of Environment, the Ministry of Energy and Mineral Resources, and the provincial governments. By doing so, the project sought to create tangible policy impacts that can protect heath and the rights of the socioeconomic minorities, such as indigenous miners.

(*) United Nations Development Program (UNDP) and the United Nations Industrial Development Organization (UNIDO)
Source: (UNIDO, 2008)

freight sector (i.e. Global Green Freight Action Plan), the remaining four projects address urban transportation. Notably, 3 of them are implemented in Viet Nam. Germany is a prominent development partner in this sector at global and regional level. The German government leads policy component of the global initiative namely “Action towards Climate-friendly Transport” (ACT). GIZ[9] and Federal Ministry of Education and Research of Germany are technical partners on urban mobility planning in ASEAN and traffic monitoring in Viet Nam respectively.

Air quality management planning: We found three initiatives that aims to establish policy framework to monitor and tackle air pollution at sources. Mongolia emphasized building capacity in analyzing and modeling air pollution to inform air quality control measures and urban development planning. Viet Nam developed integrated Clean Air Plans (CAPs) and reviewed legal frameworks and land use plans of selected cities. These two projects were assisted by German Environment Agency and GIZ respectively. At the regional level, the U.S. Environmental Protection Administration funds its Taiwanese counterpart to build capacity for South and Southeast Asia countries in addressing air and atmospheric mercury pollution such as air quality action planning, mercury monitoring, environmental education and regional exchange.

Along the lines of policy planning, we also found that many initiatives use surveillance and geospatial technologies to monitor air pollution at city and regional levels, such as SERVIR-Mekong air quality monitoring tool supported by U.S. Agency for International Development (USAID) and the U.S. National Aeronautics and Space Administration (NASA). Those technologies often aim to support policy makers in regulating pollution-induce activities.

Extractive industry pollution control: We found three projects that aim to mitigate emission and its impact on workers’ health in extractive industries. Two of them target pollution standards in the oil and gas sector by 1) establishing standard and monitoring mechanism for methane emission led by private sector, and 2) advocating for the adoption of stricter pollution standards led by a Taiwanese NGO. Notably, the project named “Awareness Campaign and Technology Demonstration for Artisanal Gold Miners” targets workers’ health by minimizing mercury releases in fume and solid forms (*see more details in Box 1*).

9 Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH, a German development agency

Black carbon reduction in agriculture and solid waste management: The Climate and Clean Air Coalition (CCAC) is leading two global initiatives on these sectors. Their main approach is to promote alternative practices and technologies to open burning of crop residues and solid waste in order to reduce black carbon emissions and the release of toxic compounds. This will have implications on the exposure of workers and farmers in these sectors, but so far the impacts of this are under-researched.

There are also ongoing efforts to curb air pollution such as promoting alternative cooling technologies led by CCAC, financing air pollution control innovations in China by World Bank and building of an eco-city in Mongolia funded by the Asian Development Bank.

5.4.3. Gender and social equity issues

Air pollution initiatives do not take into consideration labour and worker issues. None of the identified projects, except UNIDO's on mercury treatment in gold mining, explicitly concern workers' health or working conditions. Even though the cook-stove projects have direct implication on the health of domestic workers, those projects are rationalized based on energy transition discourse, such as reduction of coal consumption (Mongolia), carbon emission (Viet Nam), energy efficiency (Lao PDR). Only one project, Lao: Clean and Improved Cooking, spells out "health" and "benefit to women and children" in one of its objectives, premised on the assumption of women's singular identity as caregivers within their traditional domestic space. On the other hand, the projects that address public or outdoor air pollution might potentially reduce harmful impacts of air pollution to outdoor workers, but such impacts cannot be assumed without scientific evidence.

Technocentric solutions to air pollution overlook dimensions of vulnerability in the world of work. Framing of air pollution under climate change mitigation and energy transition discourse warrants technocentric interventions (Thompson, 2015; see also Haraway, 1988). The majority of the identified projects involved technology-based approaches such as distribution and installation of improved fuel cookstoves, constructing eco-districts and houses, creating market and promoting low-carbon transport, and monitoring GHG emissions and air quality. In addition, many of these projects advocate for policies to enable the deployment and scaling up of their technologies. These technocentric approaches neither address structural causes of air pollution, nor mitigate vulnerability to the air pollution impacts in the world of work, such as workers' exposure to air pollution, health and safety conditions, lack of access to healthcare, social and worker protection services. If these impacts are not considered, the growing informal, low-skilled migrant workers will remain the most vulnerable to the burden of outdoor and industrial air pollution.

The domination of global financial and development institutions in the framing of problems and solutions for air pollution affect how inequalities are being addressed. The main donors of the projects include the Climate and Clean Air Coalition (CCAC), World Bank, Asia Development Bank (ADB), UN agencies and international development donors. These institutions promote the discourse of climate change mitigation and green economy, which is driven by techno-sciences and market while social scientists, NGOs and civil society organizations with visions of equality and inclusion are sidelined in the framing of green economy (Hausknost et al., 2017). At the implementation level, local or grassroots actors, who have better contextual understanding of air pollution impacts on different social groups and individuals, seem to have limited access to such funds.

Chapter 6: Summary and Conclusion

This scoping study has sought to get an overview of the current understanding of how air pollution affects workers in East and Southeast Asia, with a focus on what the current state of academic research has to say on the topic. It is clear that many gaps in knowledge remain in terms of the impacts of air pollution on the working population, with informal employment being a major area lacking research and therefore data, leaving workers in the informal sector even more vulnerable to the health impacts of air pollution.

6.1 Summary of key findings

Table 6.1: Analytical matrix

	Air pollution		Emissions	Air pollution health impacts			
2019	Population weighted exposure ($PM_{2.5}$) (a)	Population weighted exposure (O_3) (a)	$PM_{2.5}$ Emissions (b)	YLLs (rate) due to ambient PM (c)	YLLs (rate) due to household air pollution (c)	YLLs (rate) due to occupational exposure (c)	$PM_{2.5}$ regulations/ limits (annual) d)
Brunei Darussalam	7.68	28.1	1.0	243.5	4.5	20.8	NA
Cambodia	22.1	39.2	143.8	644.1	2646.6	83.8	NA
China	47.7	48.9	11055.2	1987.9	509.3	222.6	35
Indonesia	19.4	37.6	1550.4	1126.1	813.0	99.2	15
Lao PDR	20.5	42.1	55.8	646.8	3084.1	95.4	15
Malaysia	16.6	38.5	86.1	822.9	8.6	59.6	35
Mongolia	38.1	43.3	25.9	2070.9	936.2	29.4	25
Myanmar	29.4	42.5	280.3	1218.4	2520.7	144.0	NA
Philippines	18.8	24.4	337.2	856.2	1145.7	66.1	25
Republic of Korea	27.4	57.9	172.6	702.1	0.5	42.4	15
Singapore	18.8	44.5	14.4	447.0	0.7	15.5	12
Taiwan (China)	23.3	42.7	110.6	902.0	37.6	71.5	15
Thailand	27.4	45.5	530.4	1023.2	232.1	81.4	25
Viet Nam	20.4	38.7	663.8	925.0	806.9	102.6	25

a) State of Global Air Report 2019 HME 2019, b) Crippa et. al, c) IHME Global Burden of Disease d) see table 5.1

Pollution levels: The data outlined in section 2 and in Table 6.1 above clearly show that while China produces by far the largest amount of $PM_{2.5}$ emissions, it is Mongolia and Indonesia which experience the highest levels of $PM_{2.5}$ concentrations, with China third – though China is first in terms of population-weighted exposure. This is consequently reflected in data on years of life lost (YLL) which shows that YLLs due to ambient air pollution are highest in China and Mongolia by a significant margin. However, when it comes to household air pollution, the highest YLLs are found in Cambodia, Lao PDR, Myanmar and the Philippines – all countries where there is still significant use of solid fuels in cooking. YLLs are highest for males across the board, even with regard to household air pollution, though the margin of difference between males and females is smaller than compared to ambient air pollution.

Employment data: The major gap in data for the region lies in data on workers in the informal sector. With regards to formal employment, the services industry takes up a large percentage share of total employment in several countries, for example in Malaysia, Philippines, Singapore and Hong Kong. In other countries, such as Lao PDR, Myanmar and Viet Nam, the major employment sector is agriculture, forestry and fishing. When comparing the labour force participation rate for males and females, the percentage gap between male and female labour force participation rate is higher for adults (ages 25+) compared to youths (15–24), suggesting that women may leave the labour force at younger ages, potentially when they start families. There is at least a 10% lower participation rate for adult (25+) females compared to adult males, while in some countries (Philippines, Myanmar and Indonesia), there is more than 30% difference in the adult male and female labour force participation rate, suggesting men are much more a part of the labour force than women in these countries.

Social dimensions of air pollution in the world of work: A review of the global literature found that the majority of papers examining the impacts of air pollution from a work perspective focus on a physical health angle, with psychological impacts less studied. Once again, studies on the informal work sector are very limited. Reviews of occupational health hazards from a gender and social equity angle tend towards biased gender roles, with many studies which focus on the impacts of air pollution on women focusing on indoor air pollution arising from domestic care responsibilities. In comparison, less focus has been paid to men and their differentiated exposures to air pollution due to gendered labor composition that is mediated along social, economic and ethnic lines. Class and power dynamics also have a bearing on air pollution exposure, with more senior and educated workers least likely to be directly exposed, such as in the coal mine.. However, considerations of race with regard to air pollution at work are lacking.

Health impacts in the workplace: For a review of East and Southeast Asian scholarship on the health impacts of exposure to air pollution in working environments, the majority of articles were from China and Taiwan, and most considered paid workers, and in an indoor context. Manufacturing workplaces were the most studied, though in terms of pollution source, road transportation was the most common source. There was nevertheless a range of work sectors considered, from printing rooms to restaurant workers to roadside vendors and office workers. The health impacts of air pollution are strongly mediated by social axes of stratification such as class, job roles, gender, age and place of residence, though indoor office workers may be exposed to more air pollution than expected.

Exposure in the workplace: The majority of the papers were once again from China and Taiwan, with transportation being the predominant source of pollutants. The level of exposure is mediated by distance between the worker and the pollutant, so within a specific industry there will be a large variation in exposure levels depending on the stage of processing. Exposure is also compounded by duration of exposure and the location of the workplace – for example, industrial parks have higher ambient background levels of pollutants. Physical barriers such as walls can offer some protection, but may not be feasible in all industries. In terms of limiting exposure and health effects, the literature mainly identified practical and individual strategies to mitigate harm, but there was little consideration of upstream prevention or a wider workforce protection angle, such as through health and social welfare coverage.

Ambient pollution regulations: The analysis shows that the majority of countries in the region have some policies and regulations in place regarding air pollution. Myanmar, Lao PDR, Cambodia have the least provision for air quality. However, it is important to note that the existence of policies does not always mean that enforcement is adequate. With regards to PM2.5 target levels, no country in the region is yet targeting the WHO guideline amount, though Singapore comes very close.

Workplace regulations: Our review found that only in Lao PDR and Mongolia was there no legal recognition of air pollutants as occupational risks, though not all countries recognized all possible types of air pollutants (particulate matter, gas and fumes and chemicals) and not all countries have provisions for compensation to affected workers. While most countries have occupational safety regulations for all waged workers, in Thailand and Singapore this is limited to industrial workers. The legal definitions of "workplace" and "employer" as employed in these various regulations suggest that informal workers are not covered by the laws. Our examination of laws regulating public space as an alternative way of potentially protecting informal outdoor workers (such as street vendors) shows that these tend to emphasize issues of access and the physical space itself, rather than less tangible issues such as air pollution.

Non-governmental initiatives: Our review found a selection of initiatives addressing air pollution in Southeast and Asia Asia, but none tackled air pollution in a labour or employment context. The existing initiatives tend to implement technocentric approaches with a focus on climate change mitigation and green economy without addressing structural causes of air pollution. They do not mitigate vulnerability to the air pollution impacts in the world of work, such as workers' exposure to air pollution, health and safety conditions, lack of access to healthcare, social and worker protection services – all of which are necessary to protect informal, low-skilled migrant workers from the burden of outdoor and industrial air pollution.

6.2 Discussion

This scoping report has sought to review the existing state of knowledge of the differentiated impacts of air pollution on workers in East and Southeast Asian countries, to help improve air quality and the quality and quantity of employment in the context of just transitions towards a low-carbon economy. The review has revealed a number of issues in terms of the framing of occupational health and safety that has implications from a gender and social equity angle.

First, there is a near-absence of consideration of workers operating in the informal sector, both from a policy perspective and from a research perspective. This may be a self-perpetuating problem: If researchers do not examine occupational exposure of informal workers, there will be no findings pushing for a need to protect informal workers from air pollution, and therefore no legal or policy framing will be developed to address their needs. We found little research of how farmers, street vendors, waste collectors and other outdoor workers are exposed to air pollution – and this gap seems to be reproduced in the policy discourse, which focuses on waged workers and employees. Exposure to pollution in agricultural work is a major gap and informal labour accounts for 90% of workers in agriculture (ILO, 2018), highlighting the need for an assessment of occupational exposure to air pollution among farm workers in the region.

Related to this, while child labour is a reality in some countries in the region, and this is explicitly forbidden in labour regulations of certain countries, such measures would only be effectively enforced in the formal employment sector. Therefore, for any children working informally, they would face the additional risks from exposure to air pollution.

Secondly, there remain gender stereotypes in framing research around occupational exposure. Most of the research on impacts of indoor air pollution focuses on women's unpaid domestic care duties and exposure to cookstove air pollution. Where there is research on occupational exposure impacts on women, the emphasis is on impacts to reproductive health.

Thirdly, there is an emphasis on the physical impacts of occupational exposure to air pollution. There is little consideration of the possible psychological impacts of air pollution, and this is reflected in health and safety legislation and regulation, which considers only the physical health impacts of air pollution.

Finally, the offered solutions to occupational air pollution exposure emphasize technical and physical solutions to mitigate emissions and exposure at the site of work. Addressing ambient air pollution remains a gap, which has negative implications for outdoor workers – many of whom operate in the informal sector, whether in urban or rural settings. At the same time, as more industries move to introduce clean and green technologies, the impacts of this need to be researched, not only in terms of exposure impacts in the workplace but on labour market demand and inequalities. Solutions also do not look to target the social inequalities in exposure to, and impact of, air pollution. For example, exposure within a single workplace can differ according to seniority, class and levels of education, with those with least power being the most-exposed to higher levels of air pollution. However, the onus should be on employers for protecting workers at all stages of the employment process, and the state should be regulating this behaviour. There could also be space for trade unions to play a role in ensuring protection is provided, and in facilitating platforms for workers to raise their concerns and contribute to the solutions and policies applied in the workplace.

Therefore, this scoping study has highlighted that there are still gaps in our understanding of air pollution in the world of work, and that the dominant legislative and research framework leaves out a significant portion of Asian workers, namely those operating in the informal sector. Section 6.3 identifies specific areas for further research.

6.3 Remaining knowledge gaps

There is a relative lack of studies on air pollution's impacts on informal workers. The majority of studies are on paid formal work where data on various labour dimensions, such as occupational health impacts and absenteeism, is more available. There is a particular lack of studies on informal paid labour.

Studies that explore the perception of workers' experiences of air pollution are scarce. While there is an abundance of studies that provide measurements on specific impacts and outcomes (e.g. health hazards) of air pollution, few studies document in detail the experiences of people exposed to air pollution, which results in fewer insights into the ways different people groups perceive, respond and adapt to air pollution. This suggests that the knowledge of impacts of air pollution are largely framed by the public health and medical discipline rather than day-to-day experiences of exposed groups.

There are no studies on the differentiated impacts of air pollution on workers who are transgender or non-binary. As discussed previously, hierarchies within a workspace can determine the type of tasks that certain individuals are assigned to. It will be interesting to further explore the ways in which discriminations around workers' sexuality and gender identity can lead to the type of work assigned and thus unequal exposure to air pollution.

Existing research on occupational health impacts of air pollution is less representative of certain worker groups and geographies. The focus on male workers in the public health domain is problematic, since a large proportion of females engage in outdoor work activities like street vending or waste picking in Southeast Asian countries like Thailand (Poonsab et al., 2019). Neglected groups include women engaging in paid work activities, farm and other rural workers, workers in small towns or from smaller and poorer countries within the region, in informal occupations, child laborers, internal migrant workers, or disabled workers. Researchers and donors should focus on understanding sources and impacts of air pollution in other under-studied regions such as the Philippines or Cambodia, or sectors that are under-studied such as mining, or with populations such as child laborers that may be at greater risk due to premature exposure to pollution.

The impact of air pollution on child laborers, as well as its subsequent gendered impacts (e.g. increased burden on caretakers) is a field that can be further explored. Only one study focused explicitly on child labor and the impacts of air pollution (Sly et al., 2019). The scarcity of insights on this topic suggests that there is a lack of targeted interventions that explicitly addresses child laborers' exposures to air pollution.

Research on physical health impacts on non-respiratory and cardiovascular systems, and on mental health, remains limited. While health impacts of air pollution on the respiratory and cardiovascular systems are well-studied, impacts on other organs such as kidney, liver, skin or the neurological or reproductive systems are relatively under-studied in the region. There was also a lack of evidence on the psychological impacts of air pollution in the search result.

More varied methodologies could be applied to study the impact of occupational air pollution to capture the socio-economic dimensions. Although one study in the search results pointed to the impact of varied hygiene practices among different worker ethnicity groups resulting in different health outcomes, more nuanced, qualitative work can be pursued to analyse intra-firm differences in job roles and hierarchies impacting exposure, stratified on the basis of race and gender. While the quantitative mixed-methods approach has provided rich preliminary evidence on the occupational health impact of air pollution in East and Southeast Asia, qualitative work such as participatory body-mapping can also provide rich data on occupational hazards, sites and contexts of exposure, especially when industrial records are inaccessible or neglected (Keith & Brophy, 2004).

Most studies on air pollution and labour focus on indoor air pollution (i.e. air quality of a particular space, such as offices) rather than outdoor air pollution (i.e. air quality of the broader environment). Furthermore, most studies on the gendered impacts of air pollution revolve around indoor air pollution, particularly around the impacts of cookstoves and within unpaid domestic labour. As measures to regulate outdoor air pollution are applied (from agricultural burning bans to industrial retrofitting), the impacts of these measures on workers' health and labour opportunities in the longer run should also be investigated.

Research could also consider whether the size of enterprises and health coverage affect the impacts of air pollution at work. Gaps in the evidence include lack of detailed information on enterprises (formal/informal, large/medium/small), as they may enable further enquiry on the effectiveness of labour and social policy legislation. Health and social security coverage of workers also need to be factored in.

A broader definition of occupational health could be applied. More evidence that adopts a broader definition of occupational health may be useful for understanding compounded vulnerabilities of certain groups of workers – such as home-based workers whose families are also at risk from air pollution, workers who reside at the site of or near polluting industries, as well as studies of the effects of pollution mitigation strategies such as temporary factory closures.

It is not clear that impacts of workers' exposure to air pollution are considered when certain policies are enacted. For example, policies to regulate the use of public spaces by outdoor informal workers or agricultural burning or emissions by taxis may see workers as sources of air pollution rather than people suffering from exposure to it, and therefore do not address the financial impact of this or the need for protective measures or clean jobs as a solution.

There are opportunities to be seized to address air pollution and climate change mitigation side-by-side while facilitating a transition to green jobs. Ways to implement this transition while also considering impacts on gender and youth and job opportunities need to be considered to avoid perpetuating or deepening inequalities and rather should be seen as an opportunity to redress these inequalities and achieve a just transition.

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Methodological annex

Annex 1: Employment and emissions by sector

Country	Employment by Economic Activity	EDGAR Emissions by sector
Brunei Darussalam		
	1) Private Services (39.21 %)	1) Road Transportation (44 %)
	2) Public Services (38.07 %)	2) Manure Management (17.2 %)
	3) Construction (8.53 %)	3) Incineration and Open Waste Burning (10.17 %)
	4) Mining and Quarrying (7.93 %)	4) Manufacturing, Industries and Construction (10.17 %)
Cambodia		
	1) Agriculture (38.21 %)	1) Biomass Burning (51 %)
	2) Private Services (27.54 %)	2) Other Sectors (30.4 %)
	3) Manufacturing (16.69 %)	3) Manufacturing, Industries and Construction (6.7 %)
	4) Public Services (8.77 %)	4) Solid Fuels (6.4 %)
Indonesia		
	1) Private Services (38.72 %)	1) Other Sectors (45.5 %)
	2) Public Services (32.74 %)	2) Biomass Burning (26.5 %)
	3) Manufacturing (15.65 %)	3) Manufacturing, Industries and Construction (10 %)
	4) Construction (7.37 %)	4) Electricity and Heat Production
Hong Kong		
	-	1) Electricity and Heat Production (81.5 %)
	-	2) Manufacturing, Industries and Construction (11.9 %)
Lao PDR		
	1) Agriculture (31.33 %)	1) Biomass Burning (51 %)
	2) Private Services (25.17 %)	2) Other Sectors (35.8 %)
	3) Public Services (17.00 %)	3) Manufacturing, Industries and Construction (6.3 %)
	4) Not Classified (12.45 %)	
Macau		
	1) Private Services (42.39 %)	1) Cement Production (33.3 %)
	2) Construction (7.86 %)	2) Shipping (28.1 %)
	3) Manufacturing (1.62 %)	3) Road Transportation (19.1 %)
		4) Electricity and Heat Production (6.4 %)
Malaysia		
	1) Private Services (44.08 %)	1) Road Transportation (23.7 %)
	2) Manufacturing (17.79 %)	2) Shipping (16.5 %)
	3) Public Services (17.77 %)	3) Biomass Burning (15.4 %)
	4) Agriculture (10.22 %)	4) Manufacturing, Industries and Construction (13.2 %)
Mongolia		
	1) Private Services (29.18 %)	1) Electricity and Heat Production (54.5 %)
	2) Agriculture (25.32 %)	2) Other sectors (19.8 %)
	3) Public Services (23.93 %)	3) Railways (9.5 %)
	4) Manufacturing (7.89 %)	4) Non-specified (9 %)
Myanmar		
	1) Agriculture (48.85 %)	1) Other Sectors (51.1 %)
	2) Private Services (27.82%)	2) Biomass Burning (37.4 %)
	3) Manufacturing (10.54 %)	3) Manufacturing, Industries and Construction (2.6 %)
	4) Public Services	4) Rice Cultivations (2 %)

Country	Employment by Economic Activity	EDGAR Emissions by sector
Philippines		
	1) Private Services (40.07 %)	1) Biomass Burning (45.7 %)
	2) Agriculture (22.86 %)	2) Other Sectors (19.5 %)
	3) Public Services (17.95 %)	3) Manufacturing, Industries and Construction (11.8 %)
	4) Construction (9.79 %)	4) Solid Fuels (5 %)
Republic of Korea		
	1) Private Services (43.6 %)	1) Manufacturing, Industries and Construction (43.5 %)
	2) Public Services (26.07 %)	2) Other Sectors (16.2 %)
	3) Manufacturing (16.19 %)	3) Electricity and Heat Production (13.2 %)
	4) Construction (7.46 %)	4) Road Transportation (12 %)
Singapore		
	1) Private Services (60.77 %)	1) Manufacturing, Industries and Construction (31.1 %)
	2) Public Services (24.16 %)	2) Electricity and Heat Production (30.8 %)
	3) Manufacturing (9.61 %)	3) Road Transportation (13.9 %)
	4) Construction (4.39 %)	4) Shipping (5.7 %)
Taiwan		
	1) Private Services (40.79 %)	1) Electricity and Heat Production (38.6 %)
	2) Manufacturing (26.66 %)	2) Manufacturing, Industries and Construction (38.5 %)
	3) Construction (7.89 %)	3) Road Transportation (10 %)
	4) Agriculture (4.86 %)	
Thailand		
	1) Private Services (32.68 %)	1) Biomass Burning (30.2 %)
	2) Agriculture (31.43 %)	2) Manufacturing, Industries and Construction (23.4 %)
	3) Manufacturing (16.28 %)	3) Other Sectors (21.36 %)
	4) Public Services (13.05 %)	4) Solid Fuels (8.7 %)
Timor-Leste		
	1) Agriculture (46.26 %)	-
	2) Private Services (35.75 %)	-
	3) Public Services (9.07 %)	-
	4) Manufacturing (9.07 %)	-
Viet Nam		
	1) Private Services (27.80 %)	1) Biomass Burning (30.3 %)
	2) Agriculture (27.78 %)	2) Other Sectors (29.9 %)
	3) Manufacturing (22.84 %)	3) Electricity and Heat Production (14.8 %)
	4) Public Services (11.12 %)	4) Manufacturing, Industries and Construction (14.7 %)

Annex 2: Method for reviewing social dimension of air pollution in the world of work

To answer the question, "What is the state of knowledge on the social dimensions of air pollution in the world of work?" we conducted an exploratory literature review to map out thematic topics and their prevalence in the literature on the social dimensions of air pollution in workspaces globally. This exploratory literature review adopted principles from systematic review and mapping methodologies to carry out a comprehensive review that seeks to minimize bias and maximize transparency. Due to time and resource constraints, a full systematic review was not possible. However, we incorporated key principles of systematic review methodology (Haddaway et al., 2015) and developed a simplified review process. This process consisted of the following steps: screening, data extraction and coding.

1. Databases

The search and review team consisted of two researchers at the Stockholm Environment Institute. The literature search was carried out during January 2021 and studies published after this time are not captured in the search. Due to time and resource constraints, the study team decided to narrow the search to only one academic database, Scopus, accessed via the Stockholm University library.

2. Search string

Before carrying out the literature search on Scopus, the research team developed a search string based on a series of search terms related to a.) air pollution, b.) social impacts and c.) work and labor. In developing these search terms, the goal was to be specific but also broad enough to capture a range of social issues. For example, instead of searching for "social impact," which could be too unspecific for the search string to yield anything meaningful, we included terms that specified the type of social impacts we are interested in exploring (e.g. gender, poverty, elderly, disability) Searches were conducted on 19 January, 2021 and have not been updated since and during the reviewing stage.

Table 1: search string

	Term 1	AND	Term 2	AND	Term 3	AND	Term 4
	"air pollution"		gender*		Impact*		workplace
OR	"air quality"	OR	wom*n	OR	outcome	OR	workspace
OR	smog	OR	girl*	OR	socioeconomic	OR	"working condition"
			elder*			OR	production
			old people			OR	livelihood
			race			OR	"occupational exposure"
			ethnicit*				labour
			poverty				workforce
			ethnic				
			poor				
			racial				
			disable*				
			vulnerab*				

Final search string: 1189 results TITLE-ABS-KEY ((*"air pollution"* OR *"air quality"* OR *smog*) AND (*gender** OR *wom*n* OR *girl** OR *elder** OR *"old people"* OR *race* OR *ethnicit** OR *poverty*

OR *ethnic* OR *poor* OR *racial* OR *disable** OR *vulnerab**) AND (*impact** OR *outcome** OR *"socioeconomic*"*) AND (*work* OR *workplace* OR *workspace* OR *"working condition*"* OR *production* OR *livelihood** OR *"occupational exposure"* OR *lab*r* OR *workforce*))

Originally, we wanted to include "men" and "boys" in our search string to capture gender aspects and to balance with the inclusion of "women" and "girls" in the search string. However, the inclusion of these two terms yielded over 5000 results, including many irrelevant articles (identified via a random check). Therefore, we decided to exclude these two terms.

Furthermore, we purposefully excluded terms related to cookstoves. While there is a wealth of literature on the gendered impacts of indoor air pollution from domestic biomass and coal burning, the purpose of our study is to look beyond this well-trodden territory and explore other gendered impacts of air pollution. However, our search string still yielded several pieces of literature on women's exposure to pollution from cookstoves. We decided to include these articles, but we are aware that the articles we have collected on this topic are not exhaustive.

Similarly, there are a wealth of existing studies on the impacts of tobacco smoke and of a phenomenon known as sick building syndrome (SBS). These terms have not been included in our search string, as it will generate many more results that will widen the scope of the search beyond the time and resource capacity of the research. A few articles related to these topics were still picked up by our search string and we have decided to include them in our analysis. However, we are aware that these articles picked up by the search string are not a full representation of the topic.

3. Screening and eligibility criteria

Articles yielded from the search string are imported into a web-based review tool, Rayaan. From there, articles are screened for eligibility at the level of title, abstract and finally, full text, according to the predefined criteria (see Table 2). Following title and abstract screening, articles that are potentially relevant are retrieved and screened in full text. Non-English articles are removed.

Table 2. Eligibility/inclusion criteria:

Relevant populations	Relevant type of exposure	Relevant outcomes
The impact of air pollution discussed within the context of labor or work (including formal, informal, domestic, paid, and unpaid work) Households, communities, workspaces, cities/towns that consist of workers who are exposed to air pollution	Explicitly about impacts of air pollution (as opposed to other forms of pollution)	Empirical data on social impacts on people, communities or social groups Reference made to issues related to gender, ethnicity/race, class, age, poverty, etc. Technical studies focusing on simulations and measurements (e.g., models to measure air pollution) and medical impacts, without discussions on the implications on the worker or broader social impacts, were not considered.

4. Data extraction and coding

A coding framework was developed to systemically analyse the articles that were included from the full text screening. The framework was put into an Excel file, which was designed to document extracted data from each article, including details such as geographical location (country), indoor or outdoor air pollution, and types of impact. See Appendix 4 for the coding framework.

5. Limitations of the methodology

Due to time and resource constraints, the initial stages of refining, testing and expanding the search string have been limited. It is expected that some literature relevant to the topic were not picked up by the search string. This can be due to the specific terms that the search string included. For example, by including specific terms on various social dimensions (e.g. gender, race, class, disability), articles that may be contextually relevant but do not explicitly address these dimensions may not have been found. Via initial testing, our team realized that an augmented search string (e.g. with the inclusion of terms such as "men," "boys," "implications" and "dimensions") could have picked up more articles that are potentially relevant. For example, a random test indicated that a relevant article, titled "Too polluted to work? The gendered correlates of air pollution on hours worked" (Montt, 2018) was picked up by an augmented search string, but not by our final search string. However, the research team decided that ultimately, the testing phase revealed that the augmented search string yielded far too many results that are beyond our time and resource capacity. Therefore, the team made the decision to simplify the search string so that it would capture a sufficient and manageable number of articles, albeit sacrificing some relevant ones.

Annex 3: Methodology for assessing evidence on the occupational health impacts of air pollution

The final search string is presented below:

(("air pollution" OR "air quality" OR "particulate matter" OR "PM*") AND ("occupational health") AND (work* OR occupation* OR production OR manufactur* OR livelihood* OR job* OR labor* OR vend* OR agricultur* OR farm* OR industr* OR factory OR factories OR firm* OR employe*) AND (gender* OR wom*n OR m*n OR male OR female OR youth* OR young OR elder* OR old OR aged OR disable* OR poor* OR rich* OR wealth* OR poverty OR "low?income" OR "socio?economic" OR vulnerable* OR marginalized OR ethnic* OR indigenous OR race

Annex 4: Methodology for assessing occupational exposure and vulnerable sub-groups

The final search string is presented below:

((“air pollution” OR “air quality” OR “particulate matter” OR “PM*”) AND (“occupational exposure”) AND (work* OR occupation* OR production OR manufactur* OR livelihood* OR job* OR labor* OR vend* OR agricultur* OR farm* OR industr* OR factory OR factories OR firm* OR employe*) AND (gender* OR wom*n OR m*n OR male OR female OR youth* OR young OR elder* OR old OR aged OR disable* OR poor* OR rich* OR wealth* OR poverty OR “low?income” OR “socio?economic” OR vulnerable* OR marginalized OR ethnic* OR indigenous OR race))

Annex 5: Method for reviewing of labour and social security policies in relation to air pollution

Search: Several databases were identified as relevant to be utilized for the national policy search, such as NATLEX, database of national labour, social security and related human rights legislation, available at https://www.ilo.org/dyn/natlex; and NORMLEX**,** information on international labour standards, as well as national labour and social security laws, including on topics such as working environment (air pollution, noise, etc.), available at https://www.ilo.org/dyn/normlex/en/. Due to the comprehensiveness of NATLEX database and the time constraints, the reviewers decided to primarily utilize NATLEX database for the policy search. However, several other key documents (foundational laws on occupational health and safety, labour, and trade union) that were not available through the database were sought out through general search on Google.

Screening and eligibility: The database yielded a vast array of social protection and labour policies from each country. The following countries were included in the screening: Brunei, Cambodia, Indonesia, Malaysia, Myanmar, Lao PDR, Philippines, Singapore, Thailand, Viet Nam, China, Republic of Korea and Mongolia. The policies were screened and selected through the following criteria:

Included:

- Documents available in English (unofficial translation, indicated by the database, also included)
- Documents available online
- Explicitly about social protection and labour by the title
- Bilateral and multilateral (e.g. ASEAN) laws on social protection and labour

Excluded:

- Technical and operational documents, such as “notifications” by ministry of labour that refer to the regulations and laws
- Vocational training laws and regulations
- Penal codes and laws related to crime and policing

Data extraction and coding: The coding framework were developed to identify areas of regulation, target groups, duty-bearers, gender and social equity considerations, and air-pollution related elements of the labour and social protection policies. Categories such as target groups and areas of regulation were easily identifiable from the title and initial paragraphs. However, in finding the specific air-pollution related elements in the documents, keywords such as “air,” “pollution,” “lung,” “vent(ilation),” “gas,” “fume” and “steam” were utilized and searched manually. Similarly, in identifying GSE themes, keywords such as “gender,” “women,” “child/ren,” “disability/ies,” “disabled,” “race” and “ethnicity” were searched in the policy documents, if the theme was not apparent from their titles. For some policy documents that were not digitally legible, meaning it is scanned or written in a way that it does not enable word or phrase search, the reviewers conducted a quick screen-through. The framework was put into the Excel file with relevant sub-categories, which is noted in the Table 3 below.

Table 3. Drop-down coding lists for policy review

Area of regulation	Target group	GSE	Duty bearer	Air pollution related
Employment protection	All workers	Gender	State	Indoor
Insurance	Women/girls	Race	Industry/business	Outdoor
Working conditions	Children	Class/poverty	Ministry of Health	Indoor and outdoor
Health and Safety	People with Disabilities	Children/youth	Ministry of Labour	None
Elimination of forced labor	Construction workers	Elderly		
Freedom of Association	Healthcare workers	Disability		
	Garment workers	Ethnicity		
	Agricultural workers			
	Domestic workers			
	Migrant workers			
	Teachers			
	Mining workers			

Limitations: Due to the search that only depended on one database, some policies that might be relevant might have been eliminated through the screening process. However, in order to mitigate such risk, some key documents (foundational laws and regulations on occupationalhealth and safety and labour code) were searched through other sources if they were not available through NATLEX. Other limitations point to the limited time that otherwise could have enabled more robust identifications and elaborations on the categories of the database.

Annex 6: Review process for initiatives addressing air pollution in the world of work

Bibliographic databases

Search string: To identify the relevant actions, initiatives and gaps, that address air pollution in the world of work, the research team developed a **search string**. The string was designed to find articles that discuss and introduce 1) program, project and campaign that aims to 2) address and tackle 3) air pollution and air quality in 4) the world of work in 5) the countries of interest (see Table 4 for more detail and synonyms used). The search string was searched by title, abstract and keyword on Scopus.

Table 4. Search string

	Term 1	AND	Term 2	AND	Term 3		Term 4	AND	Term 5
	project		address		"air pollution"		workplace		Brunei
OR	program	OR	solv*	OR	"air quality"	OR	workspace	OR	Cambodia
OR	campaign	OR	tackl*	OR	smog	OR	"working condition"	OR	Indonesia
		OR	reduc*			OR	production	OR	Lao
		OR	decreas*			OR	livelihood	OR	Malaysia
		OR	curb			OR	"occupational exposure"	OR	Myanmar
						OR	labour	OR	Philippines
								OR	Singapore
								OR	Thailand
								OR	Vietnam
								OR	China
								OR	Macau
								OR	"Hong Kong"
								OR	Mongolia
								OR	"South Korea"
								OR	Taiwan

(project OR program OR campaign) AND (address OR solv* OR tackl* OR reduc* OR decreas* OR curb) AND ("air pollution" OR "air quality" OR smog) AND (workplace OR workspace OR "working condition" OR production or livelihood OR "occupational exposure" OR labour OR labor) AND (Brunei OR Cambodia OR Indonesia OR Lao OR Malaysia OR Myanmar OR Philippines OR Singapore OR Thailand OR Vietnam OR China OR Macao OR "Hong Kong" OR Mongolia OR "South Korea" OR Taiwan)

Screening and eligibility criteria: A researcher filtered the articles by the relevance of the title: thematic focus on air pollution, regional focus of Asia, and some relevance to the world of work, utilizing Rayyan QCRI systematic review software. The irrelevant articles were labelled with exclusion reasons, i.e., outside of regional focus, not a relevant actor and unrelated topic. Another researcher on the team randomly scanned these articles to validate the outcome. The articles that passed the first round of screening entered the second step, reviewing the abstract. After the abstract review, the full text of the articles was then retrieved and examined in depth for the specific programs, projects, and initiatives that were elaborated in their contents (see the eligibility and inclusion criteria in Table 5). The relevant initiatives were put into a database (Excel spreadsheet) containing project title, project holders, partners, target groups, approach, scope of intervention, expected outcomes and impacts, and links to the project document and information.

Table 5. Integrated eligibility and inclusion criteria:

Relevant actors	Relevant type of exposure	Relevant outcomes
Initiatives by non-governmental actors (not led by the states, although they might be the beneficiaries) Projects, programs, and campaigns conducted in following countries: Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, Viet Nam, China, Macau, Hong Kong, Mongolia, Republic of Korea, or Taiwan	Explicitly about the impacts of air pollution (as opposed to other forms of pollution)	Exclude technical studies with a sole focus on medical and health impacts as well as scholarly works that only focus on modeling for air pollution and quality Include project, programs, and campaigns with information on concrete project outputs and/or policy and action recommendations

Results: The search result from Scopus identified 211 articles (duplicates eliminated). Then, the research team identified 11 articles relevant to the topic after reviewing the abstract. From these 11 articles, however, only one article showed its relevance according to the selection criteria after the full-text analysis. The majority of the articles identified through abstract review indicated research projects that examined air pollution through pollution monitoring, especially in China where six out of 11 projects were conducted. Meanwhile, only one article out of all items identified from Scopus indicated a project with a concrete policy output which was “GIS Based Urban Design for Sustainable Transport and Sustainable Growth for Two-Wheeler Related Mega Cities like HANOI” authored by (Ruhe et al., 2013) that elaborates Real Time Monitoring of Urban Transport (REMON) project. REMON project aims to reduce air pollutants and emissions in the urban transport sector of Hanoi, Vietnam through the development of a comprehensive traffic monitoring system and its integration into the existing national traffic management. These projects were eventually excluded from the later processes of screening when the researchers examined the project document.

Manual search

Key words: We conducted a manual Google search of projects and programs, using keywords: “air AND (pollution OR quality) AND (campaign OR program OR project) AND (country name)”[3]

The search results were significantly overlapping with each other: for example, substituting the word “program” for “project” more or less resulted in the same search output.

Screening process: A researcher first collected the documents, websites, and news articles on projects, programs, and campaigns on air pollution based on the relevance of their titles. Then, the full text documents and project information on official websites were examined. The researcher compiled relevant projects and campaigns as well as their detailed information into the database under the same categories utilized in the bibliographic search. Again, a researcher who did not take part in the filtering process scanned the projects to validate the search outcome.

While there were many technical websites and documents (e.g. air quality monitoring tools run by private or public actors), our focus was to find non-governmental initiatives and actions with policy and result-oriented information available online. Meanwhile, some of the initiatives that indicated governmental actors (e.g. Ministry of Labor) as a beneficiary or a partner were also included in this search.

The relevant information from the documents and websites were compiled into a database that contains project title, project holders, partners and target groups, approach, scope of intervention, expected outcomes/impacts, and other relevant information. From this compilation, projects pertinent to air pollution in the world of work have been identified. Also, various international and regional organizations tackling issues of air pollution were identified and listed in the database.

Results: This search method enabled the double- and triple-screening of the search results to find relevant documents or information. However, the Google search output showed much more scholarly and academic articles on air pollution with health and medical effects rather than reports or information on air pollution initiatives led by international, regional and local non-governmental actors. Also, even if the initiatives were relevant from the title, many of them did not show sufficient relevance to the world of work.

During the manual search, the research team scanned documents and websites indicating projects or programs. After further examining the project information (i.e. through the official project website, end-of-project report, info sheets, news articles and blog posts), the team compiled 23 initiatives that showed the most relevance to air pollution in the world of work. The final database was developed based on these 23 initiatives.

Limitations: Both data sources and related search methods have limitations that affect the number of identified initiatives. The bibliographic database mainly contains research articles on air pollution impacts and technologies. After reviewing the abstract, we arrived at 11 articles relevant to the topic. These projects were eventually excluded when the researchers examined the project document. On the other hand, for manual search on Google, the researcher only scanned the first 50 results per search string due to diminishing relevance of the yield and the constraints of time. In addition, many initiatives and projects led by civil society, grassroots and private actors might have not been detected by the search string and keyword searches. For example, the occupational health and safety initiative led by Confederation of Mongolian Trade Unions (CMTU), where they provided trainings and awareness-raising events to decrease the impacts of air pollution for all trade members, including members of women and youth committees[10], were not identified from the searches despite its close relevance to this task. Another example is cookstove projects. Although cookstove initiatives are widespread in Asia, the search string and keyword search only picked up a small collection of the projects related to this topic, which may point to the fact that cookstoves are used mainly in domestic settings and domestic work is not recognised as work. We were also limited to information available in English. To such limitations, future research can further contextualise the search strings and keywords with sufficient time allowed to identify relevant initiatives and actions depending on the national and regional context.

10 Through email exchanges with CMTU, March 16 – 24, 2021

Annex 7: Initiatives on air pollution

	Project title	Project holders	Links to project information
1	Switch Off Air Pollution (2018–2021)	Geres Acting for Climate Solidarity, Building Energy Efficiency Center (BEEC), People in Need (PIN) with Ger Community Mapping Center (GCMC), Mongolian National Construction Association (MNCA)	https://www.switch-asia.eu/site/assets/files/1538/soap_eng_factsheet.pdf
2	Clean Air Green Cities, Vietnam	Viet Nam Green Generation Network, Center for Living and Learning for Environment and Community (Live & Learn) with Center for Supporting Green Development (GreenHub) and Hanoi Department of Natural Resources and Environment	https://www.greenhub.org.vn/cagc/ https://www-origin.usaid.gov/sites/default/files/documents/1861/FS_CleanAir-GreenCities_Oct2019-Eng.pdf
3	Heating culture improvement pilot project for reduction of air pollution in Mongolia (2008–2009)	Korea International Cooperation Agency (KOICA)	https://www.oecd.org/derec/korea/Ex-post-Evaluation-Report-on-the-Pilot-Project-to-Reduce-Air-Pollution-by-Improving-Heating-Culture-in-Ulaanbaatar-Mongolia.pdf
4	Lao: Clean and Improved Cooking	Carbon Initiative for Development (Ci-Dev) of World Bank	https://www.ci-dev.org/programs/lao-clean-and-improved-cooking
5	Improved Cookstove Progamme Lao PDR	Oxfam, Normai (Lao PDR), SNV Netherlands Development Organization	https://www.switch-asia.eu/project/improved-cook-stove-programme-lao-pdr/
6	Action towards Climate-friendly Transport (ACT) initiative	Transformative Urban Mobility Initiative (TUMI)	http://www.transformative-mobility.org/news/do-you-act-iact
7	The Green E-Transportation Initiative	United Nations Development Programme (UNDP)	https://www.vn.undp.org/content/vietnam/en/home/blog/the-green-e-transportation-initiative--green--clean-and-smarter-.html
8	Sustainable Mobility in Medium-Sized Metropolitan Regions in ASEAN (SMMR)	implemented by GFA Consulting Group and partners on behalf of Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ).	https://smmr.asia/project-scope/
9	CCAC: Global Green Freight Action Plan	CCAC	http://climateinitiativesplatform.org/index.php/CCAC:_Global_Green_Freight_Action_Plan
10	Real Time Monitoring of Urban Transport (REMON) - Vietnam	Federal Ministry of Education and Research of Germany	https://www.fona.de/medien/pdf/Projektbeschreibung_Vietnam_REMON_bf.pdf?m=1558345778&
11	CCAC Oil & Gas Methane Partnership (OGMP)	UNEP Paris	http://climateinitiativesplatform.org/index.php/CCAC:_Oil_%26_Gas_Methane_Partnership
12	Awareness Campaign and Technology Demonstration for Artisanal Gold Miners	Global Environmental Facility (GEF), with the United Nations Development Program (UNDP) and the United Nations Industrial Development Organization (UNIDO)	https://iwlearn.net/resolveuid/319d36769374ddf2b24bbc65afb0918f
13	Campus Air-Pollution Flag Program in 2014	Citizen of the Earth Taiwan (CET)	https://www.cet-taiwan.org/about/english

	Project title	Project holders	Links to project information
14	The South & Southeast Asia-Air Improvements in the Region (SSEA-AIR) program	Environmental Protection Administration (EPA) and Environmental Protection Administration Taiwan (EPAT)	https://www.epa.gov/international-cooperation/collaboration-environmental-protection-administration-taiwan-epat
15	Integrated air quality management (AQM) and climate change mitigation in the framework of the World Bank's Pollution Management and Environmental Health (PMEH) Programme	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH	https://www.international-climate-initiative.com/en/details/project/integrated-air-quality-management-aqm-and-climate-change-mitigation-in-the-framework-of-the-world-banks-pollution-management-and-environmental-health-pmeh-programme-17_I_355-2865
16	Further development of air quality control planning and air quality monitoring in Ulaanbaatar (Mongolia)	German Environment Agency (in cooperation with the Mongolian Governmental Implementing Agency for Meteorology and Environmental Monitoring)	https://www.umweltbundesamt.de/sites/default/files/medien/3662/beratungshilfe/info_67_3_en.pdf
17	SERVIR-Mekong Air quality explorer	U.S. Agency for International Development (USAID) and the U.S. National Aeronautics and Space Administration (NASA)	https://aqatmekong-servir.adpc.net/en/mapviewer/
18	Capacity Development Project for Air Pollution Control in Ulaanbaatar City Phase 2 in Mongolia	Japan International Cooperation Agency (JICA)	https://openjicareport.jica.go.jp/pdf/12289195.pdf
19	Promoting HFC Alternative Technology and Standards	CCAC	https://www.ccacoalition.org/en/initiatives/hfc
20	Mitigating short-lived climate pollutants from the municipal solid waste sector	CCAC	https://www.ccacoalition.org/en/initiatives/waste
21	Ulaanbaatar Green Affordable Housing and Resilient Urban Renewal Project (AHURP)	Asian Development Bank	https://www.adb.org/projects/49169-002/main https://www.adb.org/sites/default/files/project-document/177633/49169-001-pptar.pdf
22	Innovative Financing for Air Pollution Control in Jing-Jin-Ji	World Bank	http://documents1.worldbank.org/curated/en/488161468187136819/pdf/102272-PAD-P154669-R2016-0031-1-OUO-9.pdf
23	CCAC Agriculture Initiative	CCAC	https://www.ccacoalition.org/en/initiatives/agriculture

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